Sensors and Control Systems in Bio and Environmental Engineering

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Outline

- Monitoring and Controlling the Systems
  - Tissue Bioengineering
  - pH, Oxygen, Carbon Dioxide and Glucose Sensors
- Environmental Monitoring
  - Acoustics
  - Air and Water
  - Radiation
- Summary

pH Sensor - Requirements

Requirements

- Monitor the pH of a sterile solution in the pH range of 6.5 to 7.5

  within +/- 0.1 pH

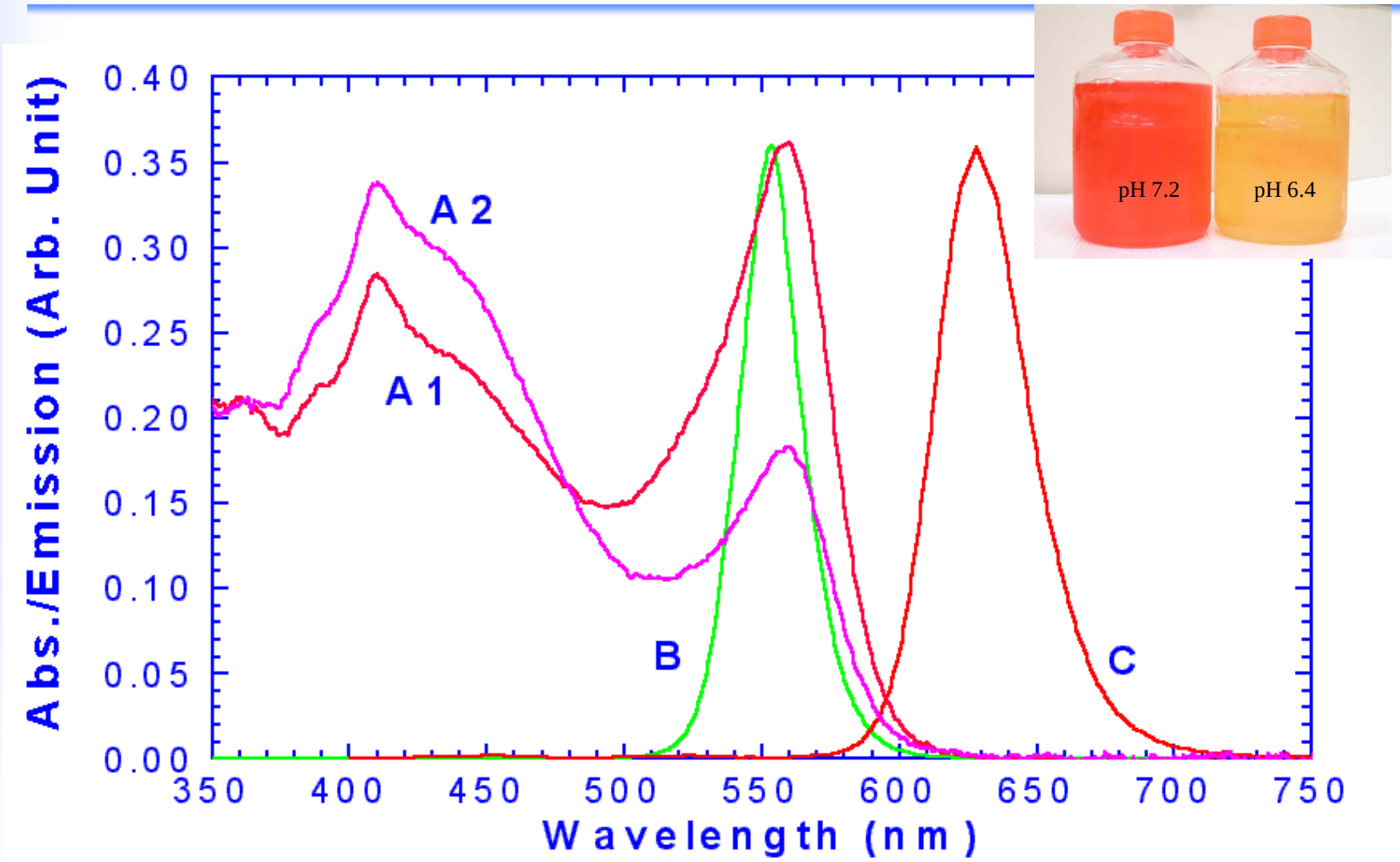
- Working Conditions : 37 deg C; 5 to 10 % CO_2; 95 % humidity
- Mass, Volume and power should be minimal (defined)
- Single calibration for 90 days

  Withstand biofouling of the sensor due to cell debris

  and protein; microbubbles

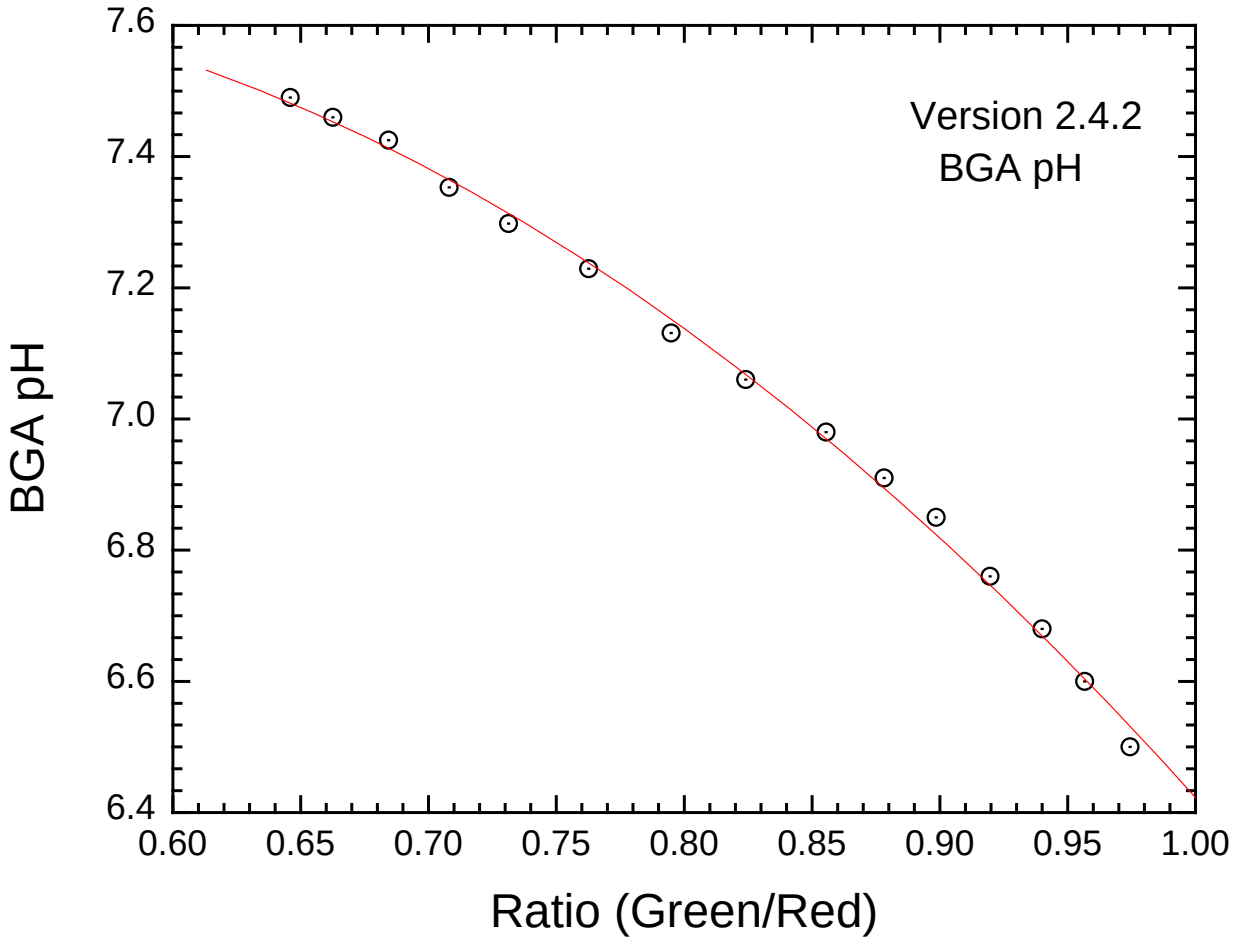
- Components compatible to microgravity; Launch conditions
- Preferably no consumables during 90 days

Optical pH Sensor

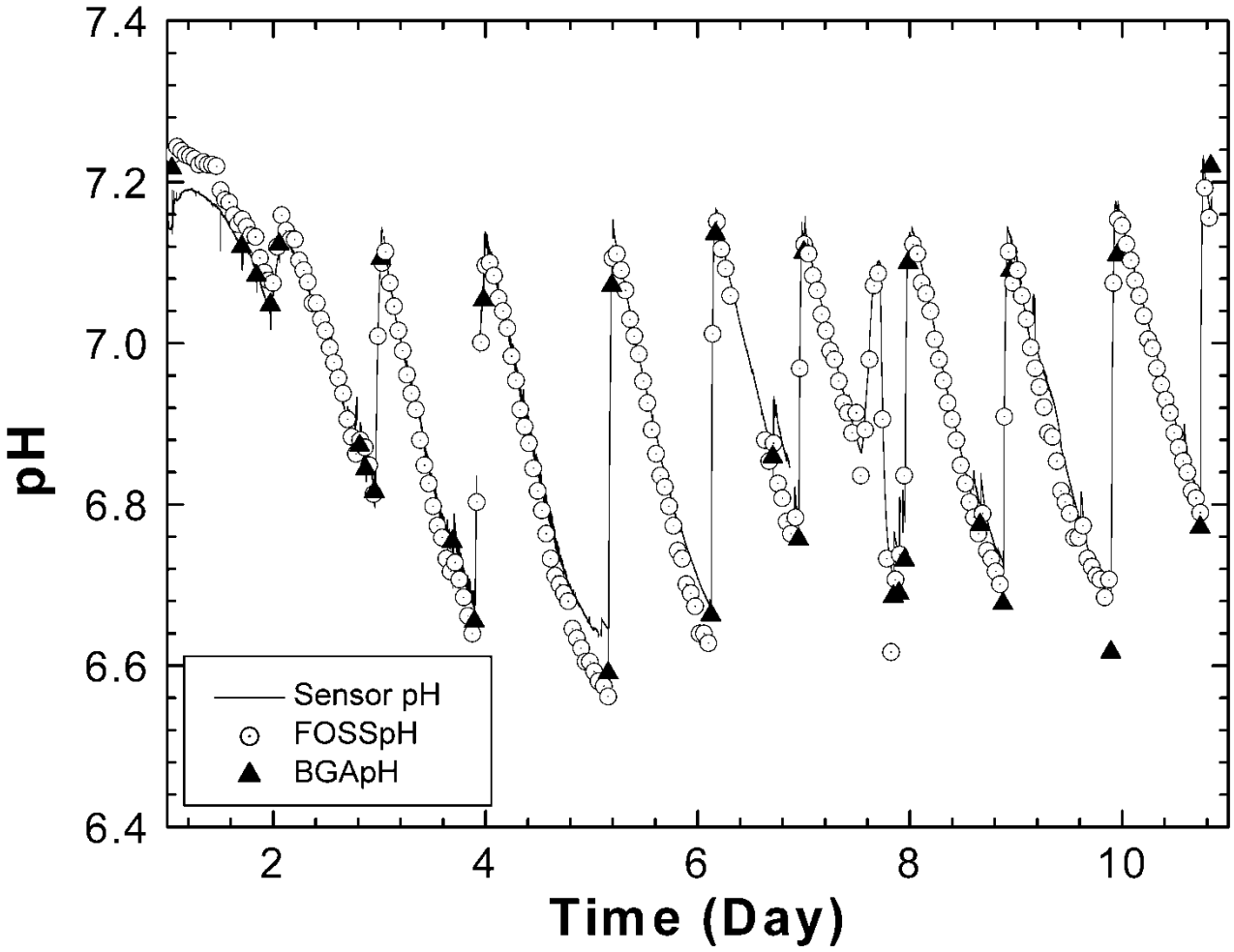


(A) Optical Absorption Spectrum of GTSF-2 Media at pH 7.49 (A1) and 7.06 (A2); Emission Spectra of (B) Green and (C) Red Light Emitting Diodes

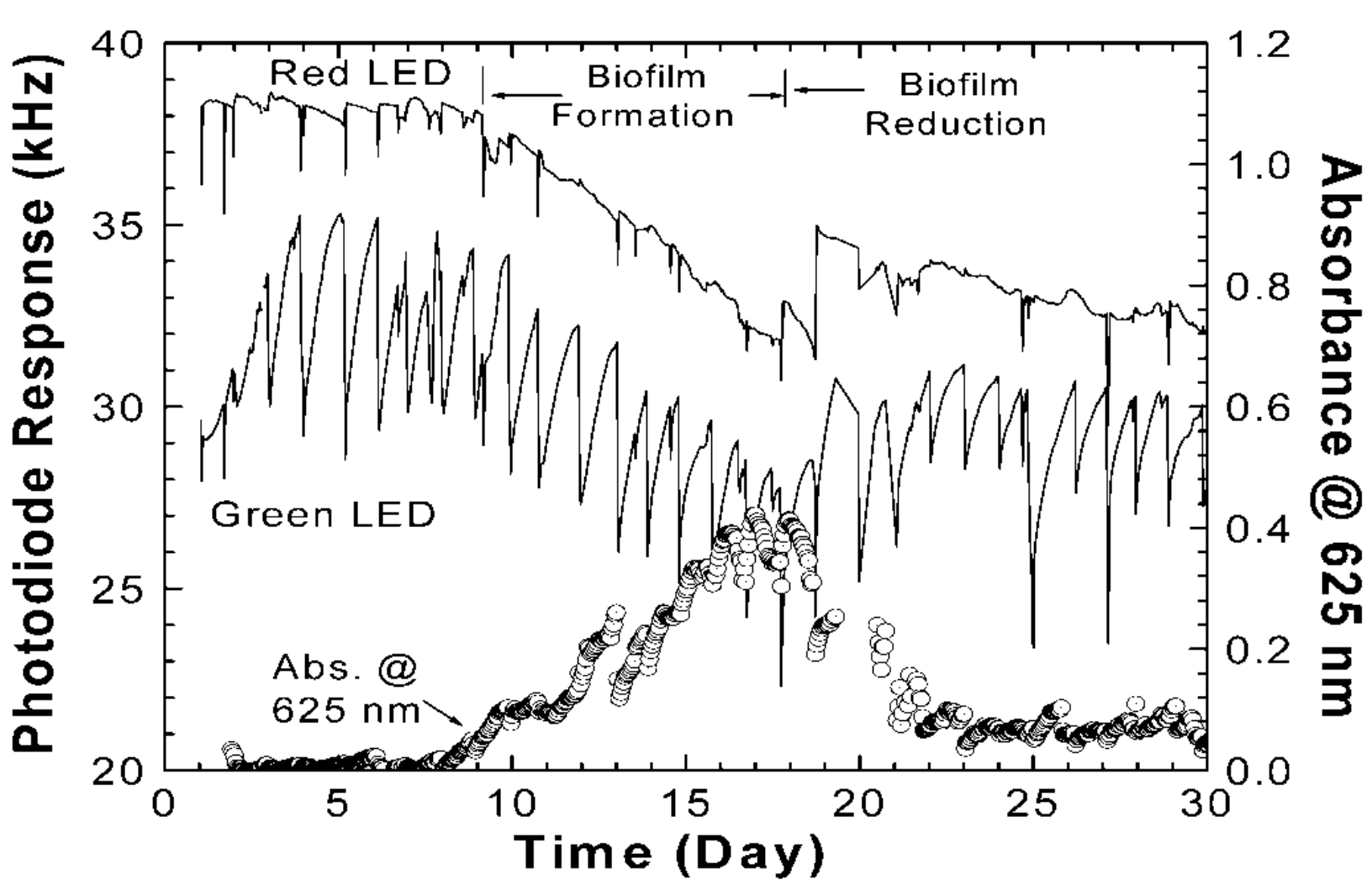
Calibration Graph of the pH Sensor



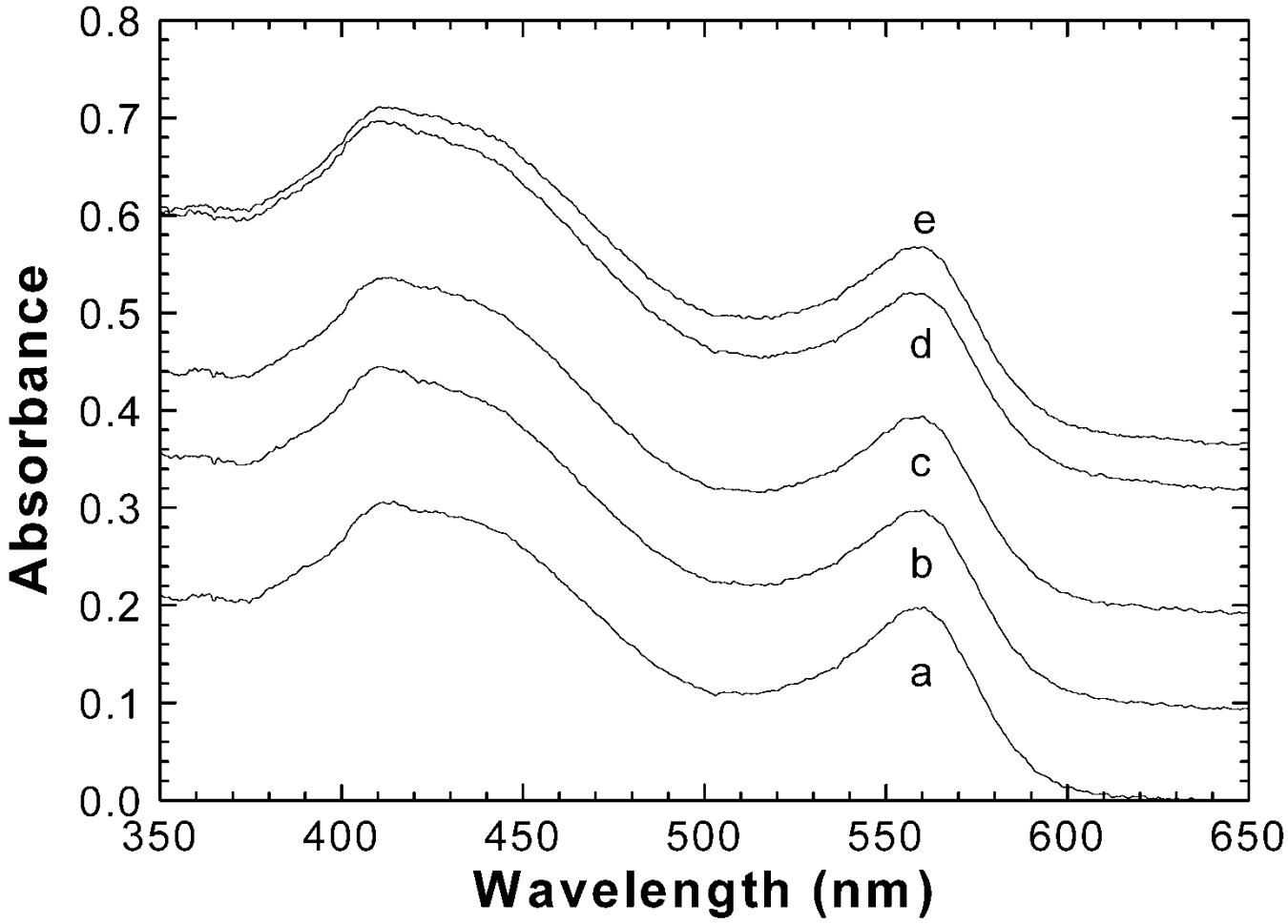
Performance of a pH Sensor in a Bioreactor Cell Run (BHK-21 Cells)



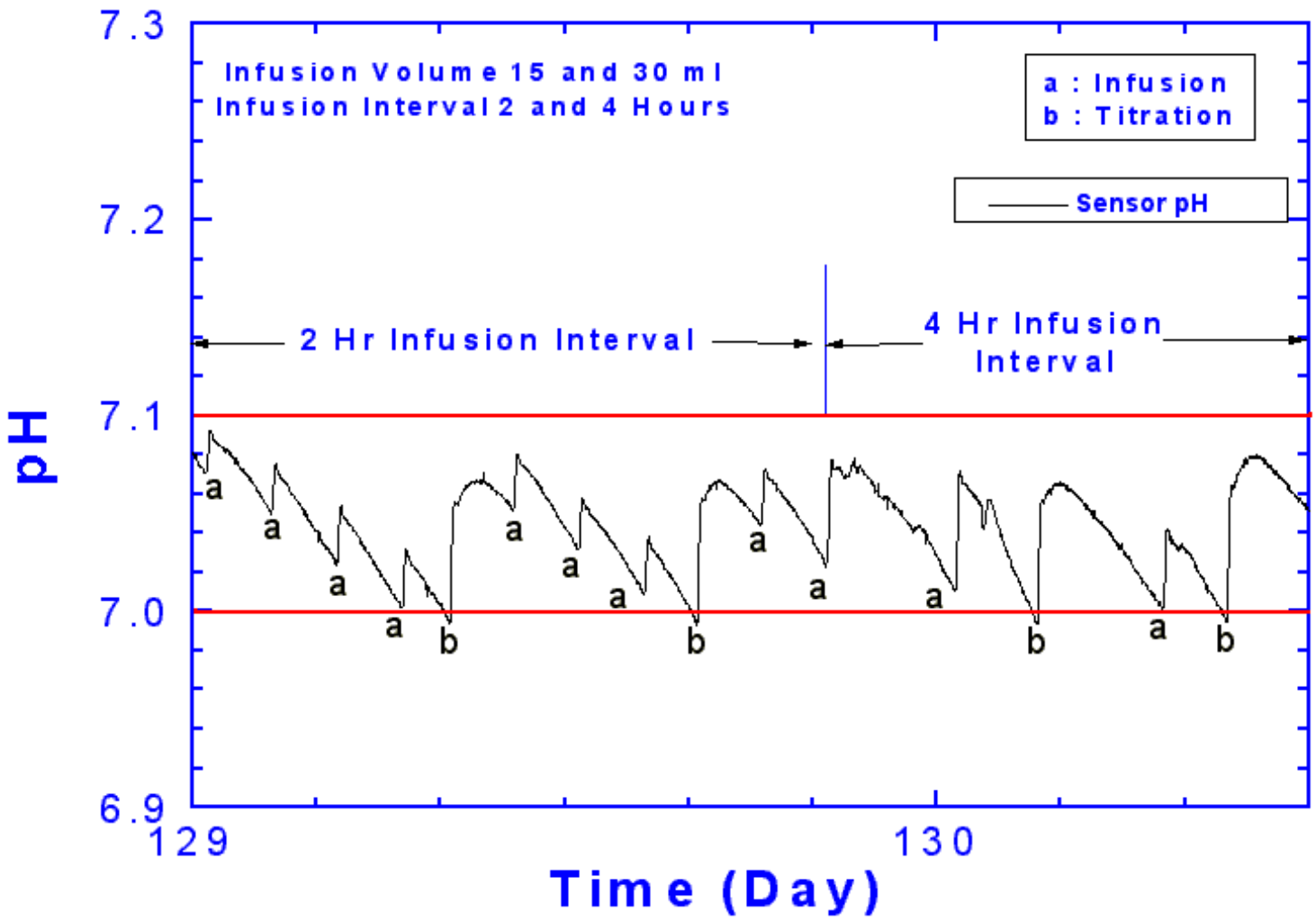
Biofouling


Red LED
Biofilm Formation
Biofilm Reduction
Green LED
Abs. @ 625 nm
Photodiode Response (kHz)
Absorbance @ 625 nm
Time (Day)
40
35
30
25
20
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30

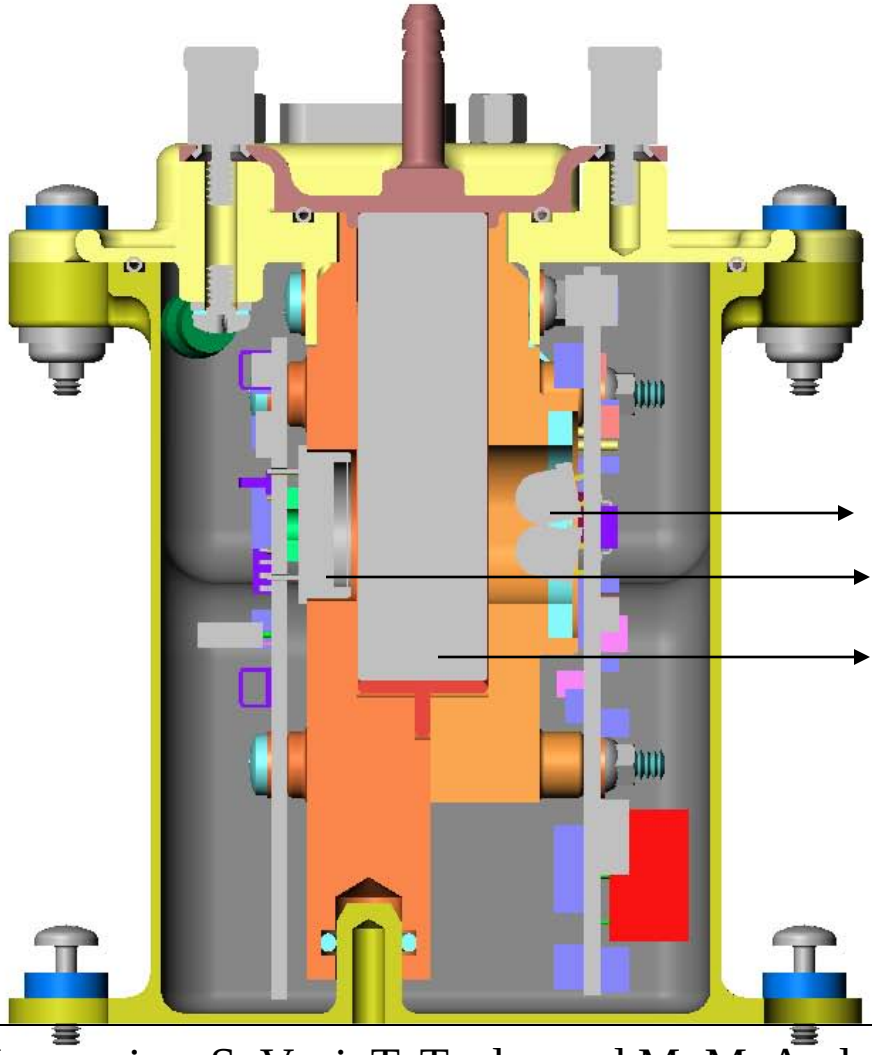
Biofilm Formation inside the Optical Cuvette of the pH Sensor Monitored by Fiber-optically Coupled Spectrophotometer at 4, 9, 15, 17 and 21 Days



pH Control in a Perfused Bioreactor



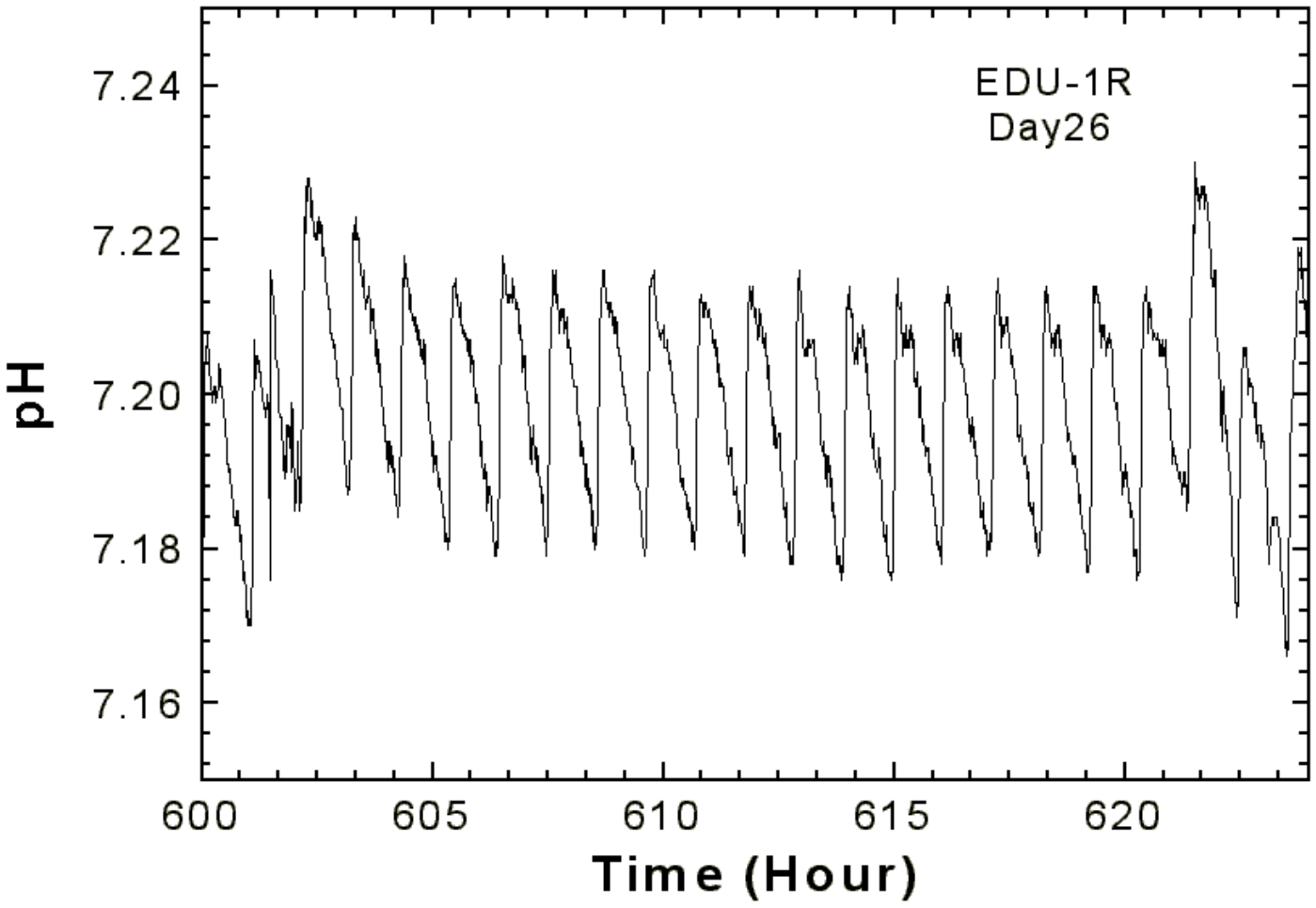
Cross Section of Flight Hardware pH Sensor Prototype



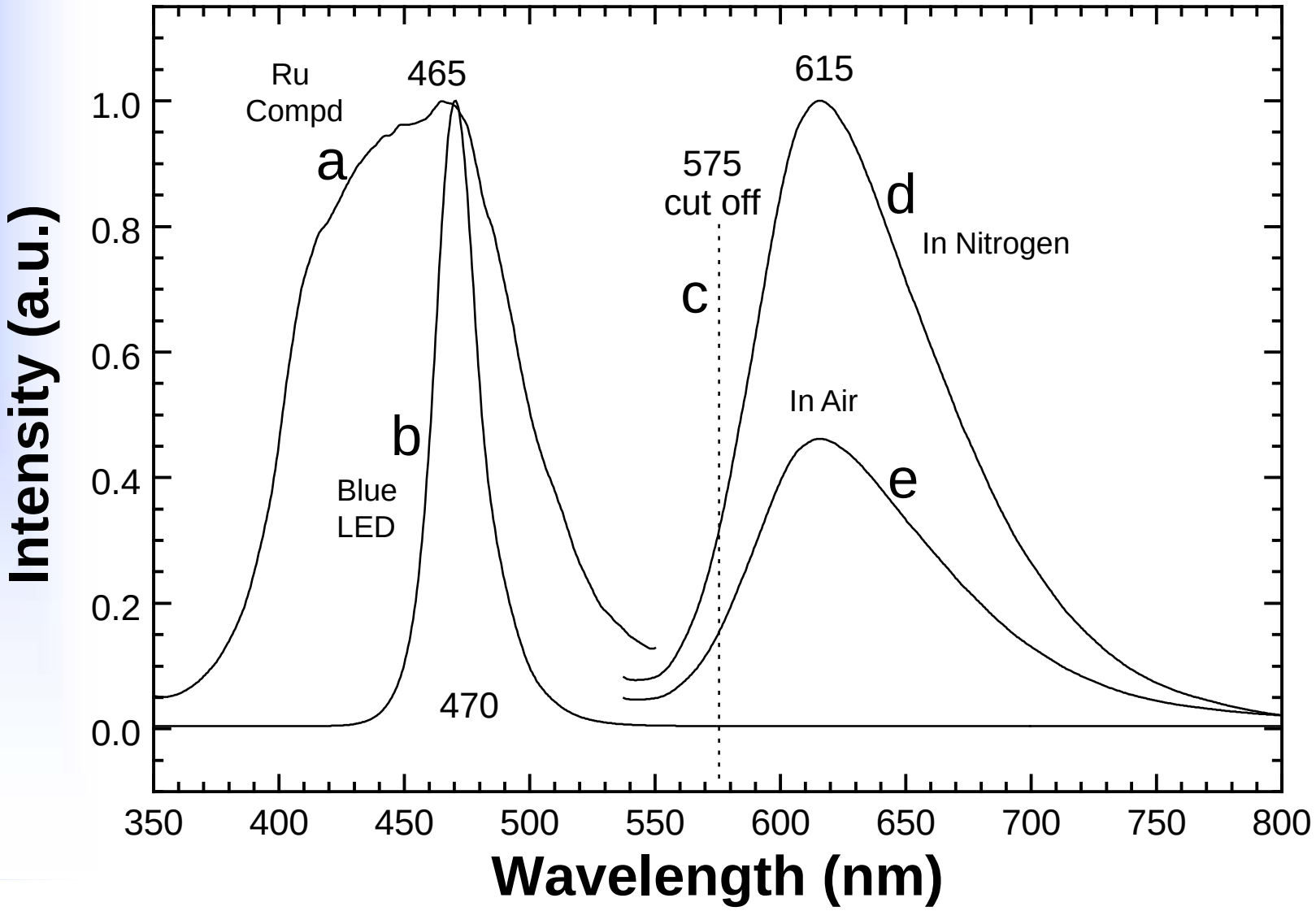
A. S. Jeevarajan, S. Vani, T. Taylor and M. M. Anderson, *Biotech. and Bioeng.*, **78**, 467-472 (2002)

Continuous Monitoring of pH using pH Sensor in a Flight Bioreactor

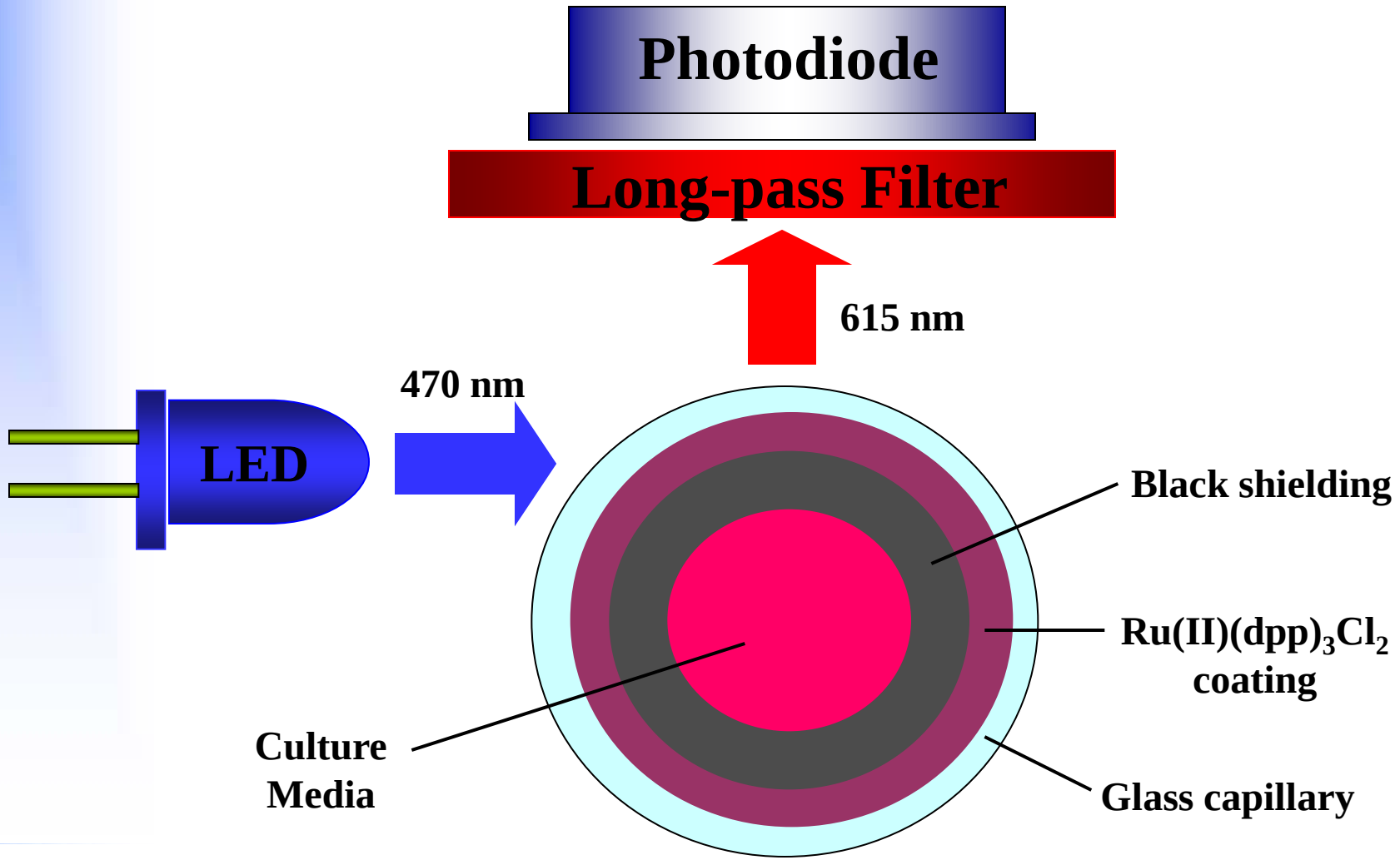
Media (30 ml) was infused every hour and pH window of 0.0



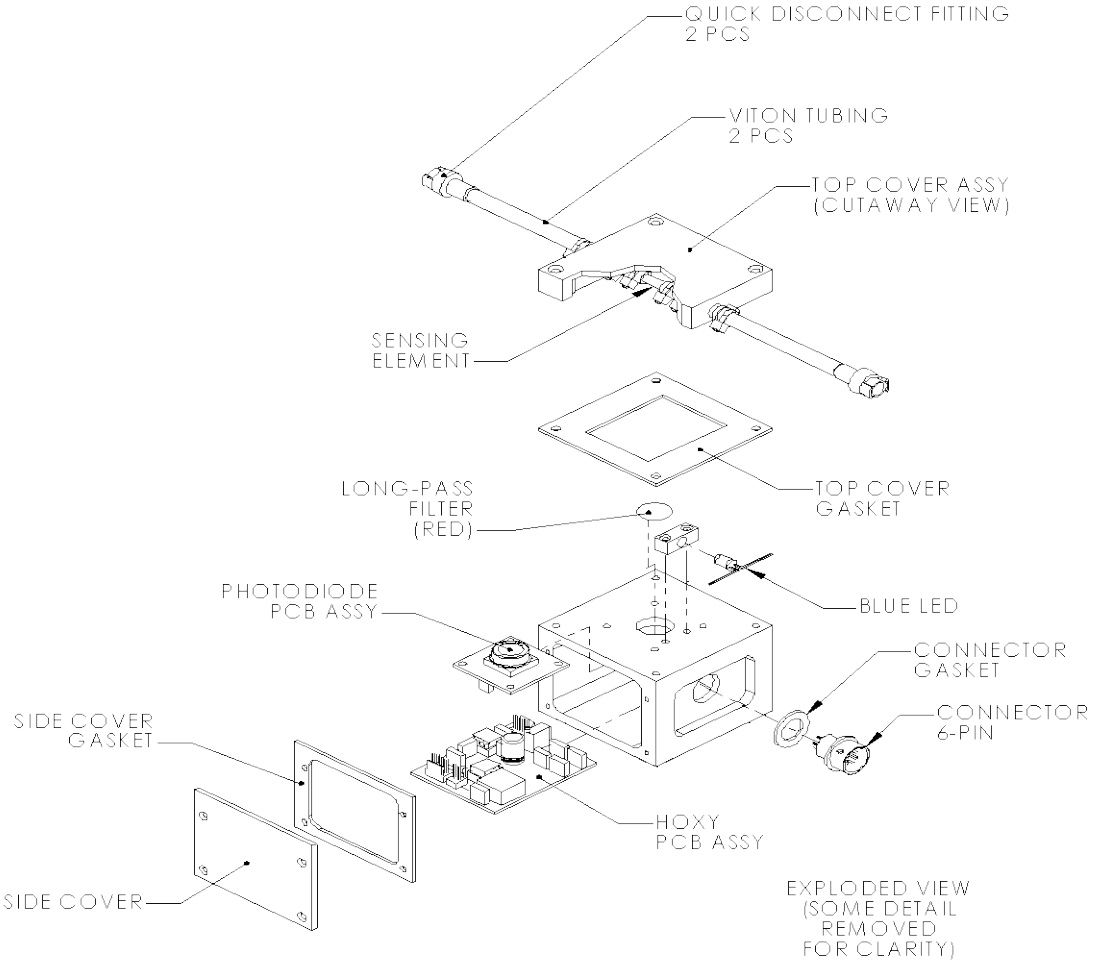
Oxygen Sensor - Fluorescence



Schematic Diagram of the Oxygen Sensor

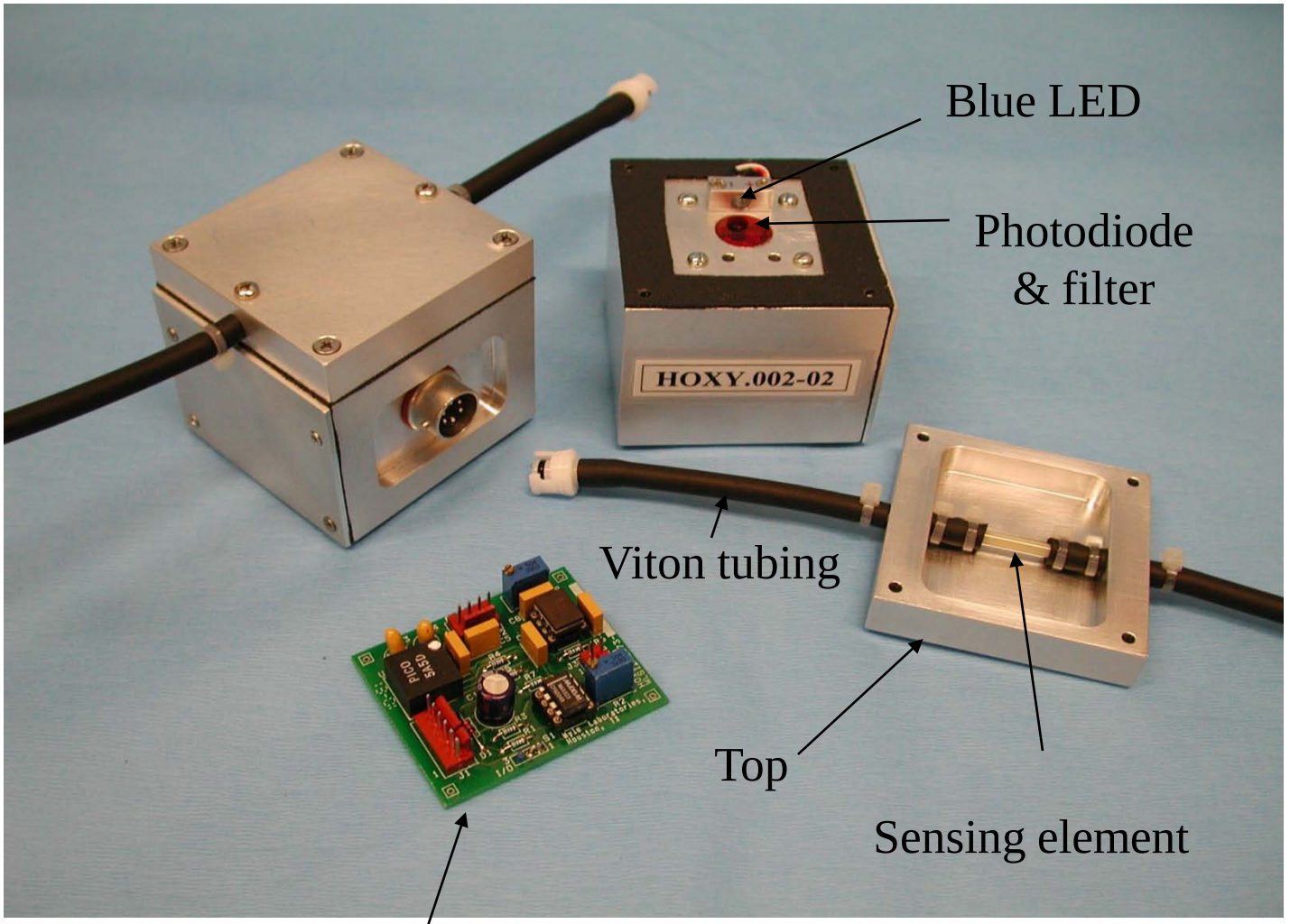


Exploded View of the Oxygen Sensor

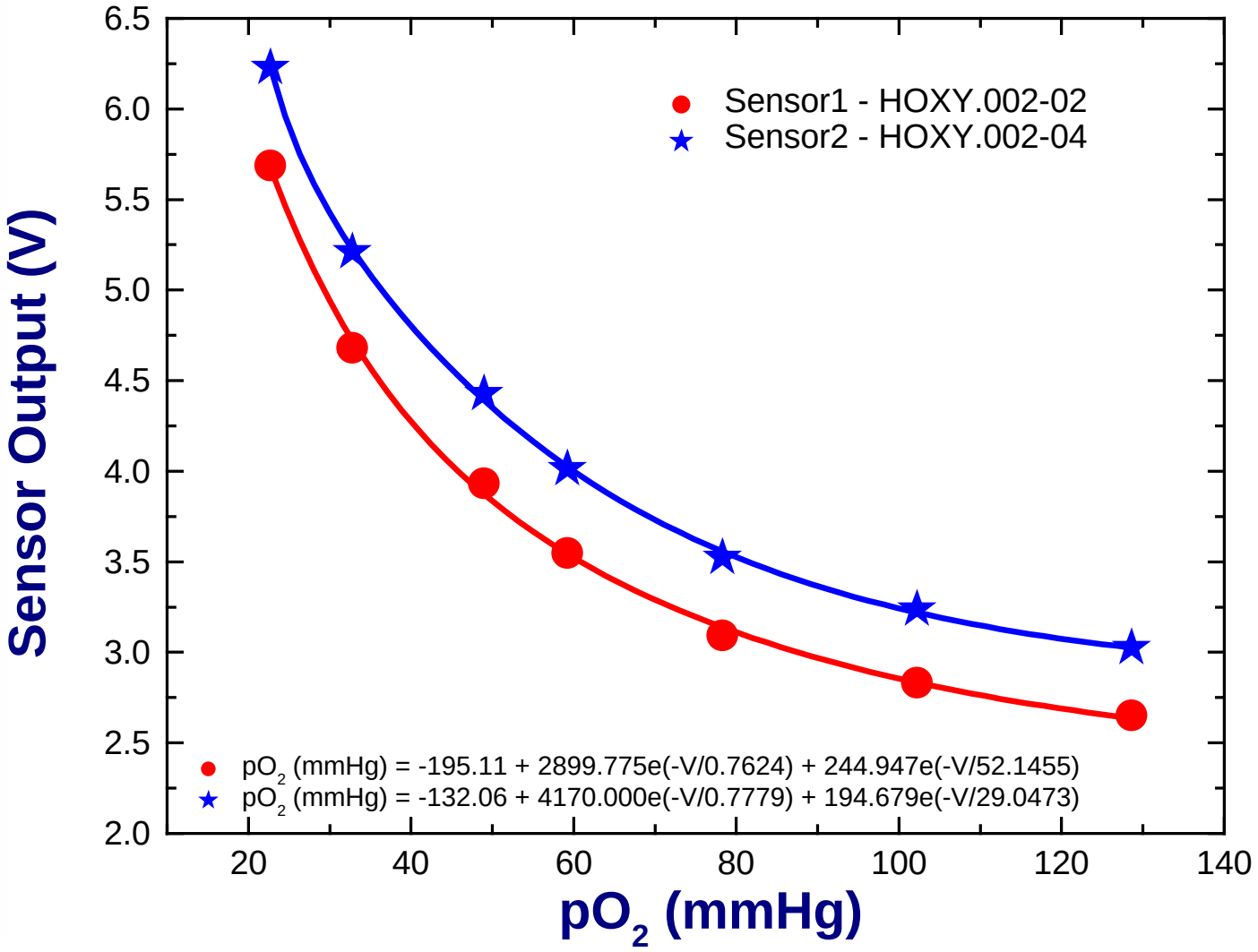


OXYGEN SENSOR

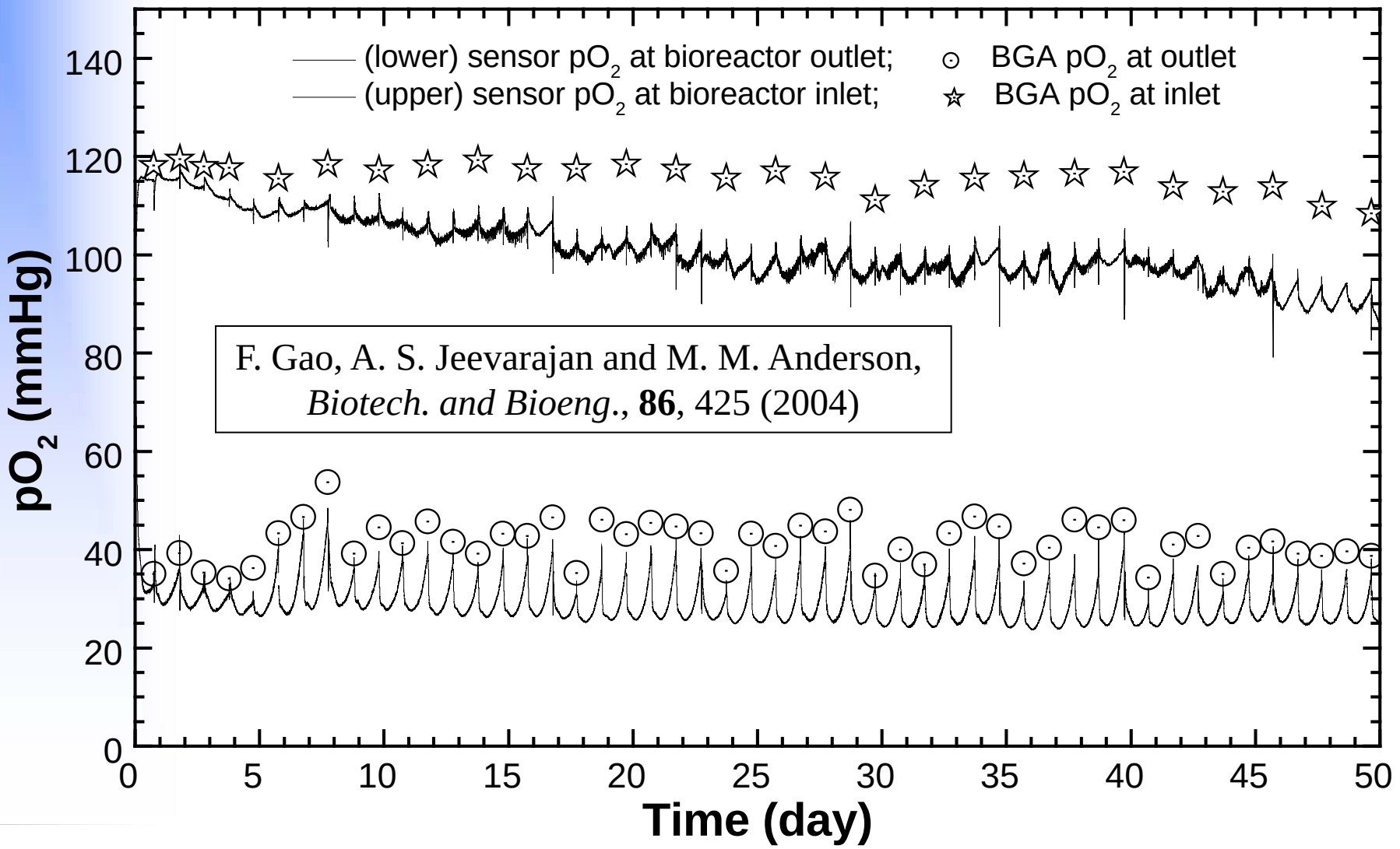
HOXY Optical Oxygen Sensors



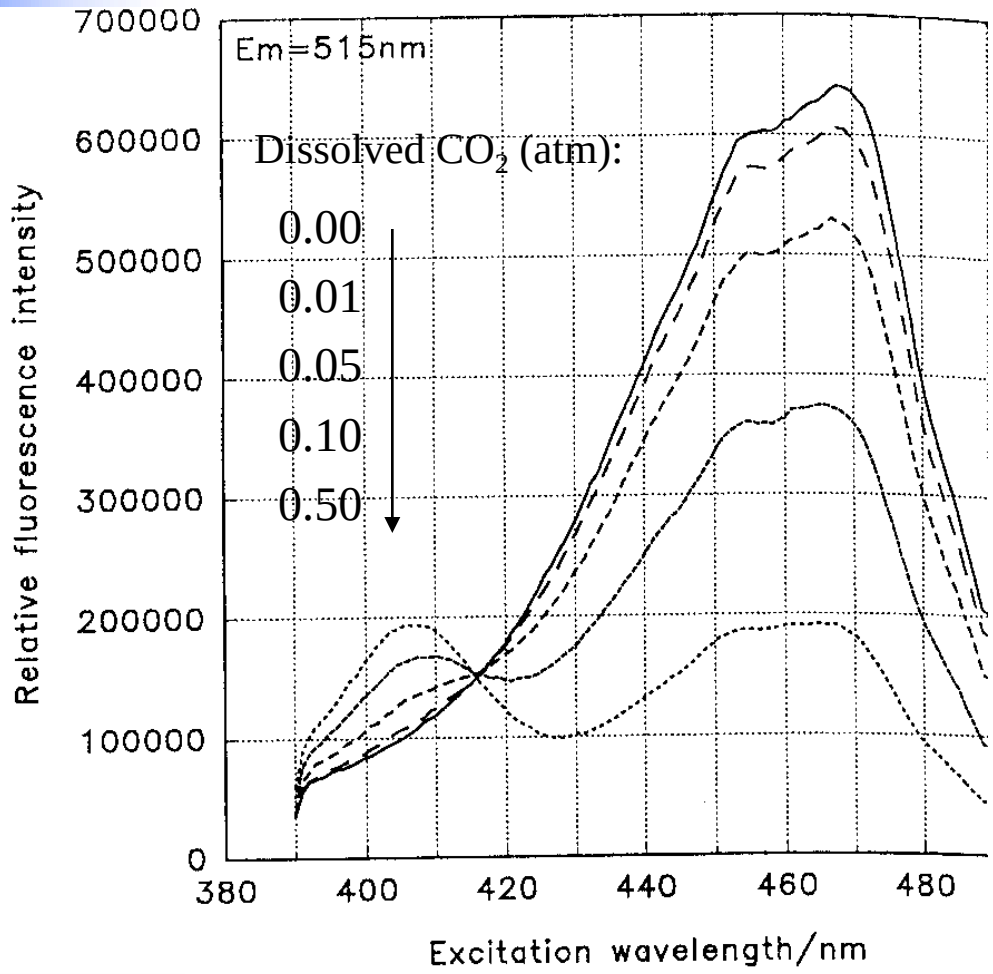
Calibration Curves of HOXY Oxygen Sensors



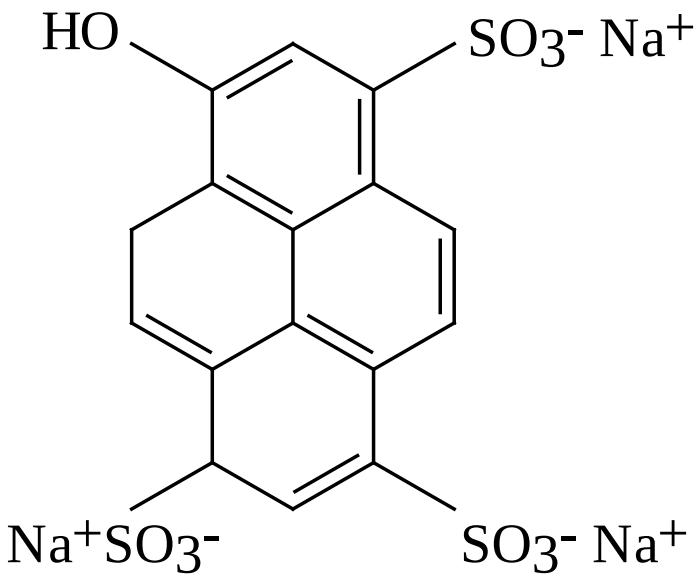
Performance of the Oxygen Sensor in a Cell Run



Excitation spectra of HPTS at various dissolved CO_2 concentrations at emission of 515 nm

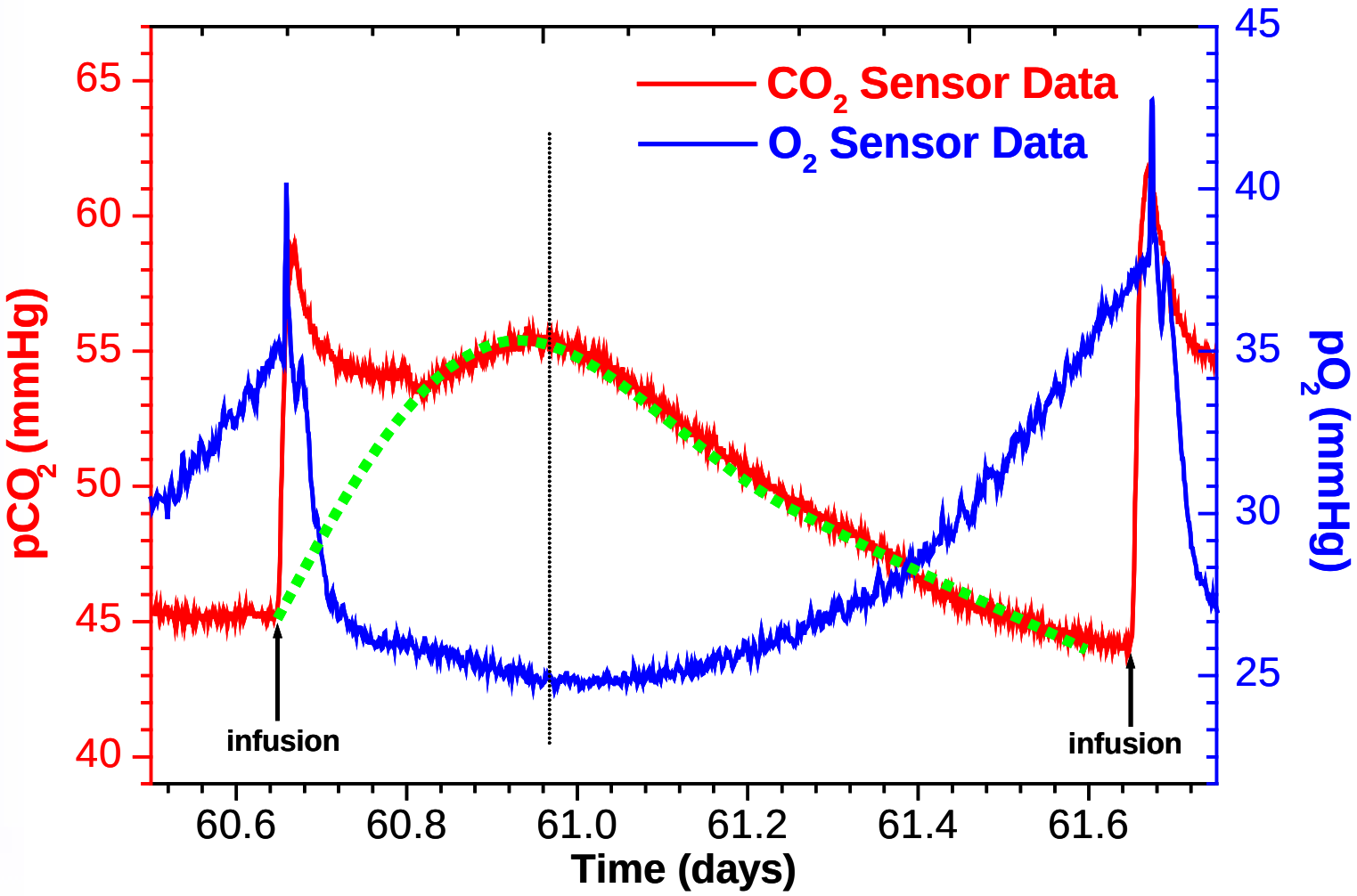


pKa = 7.3



8-hydroxy-1,3,6-pyrenetrisulphonate

Oxygen and CO_2 Sensor Data for One Day



An Amperometric Glucose Sensor System

$$\text{Glucose} + O_2 \xrightarrow{\text{GOx}} H_2O_2 + \text{Gluconic acid} \quad (1)$$

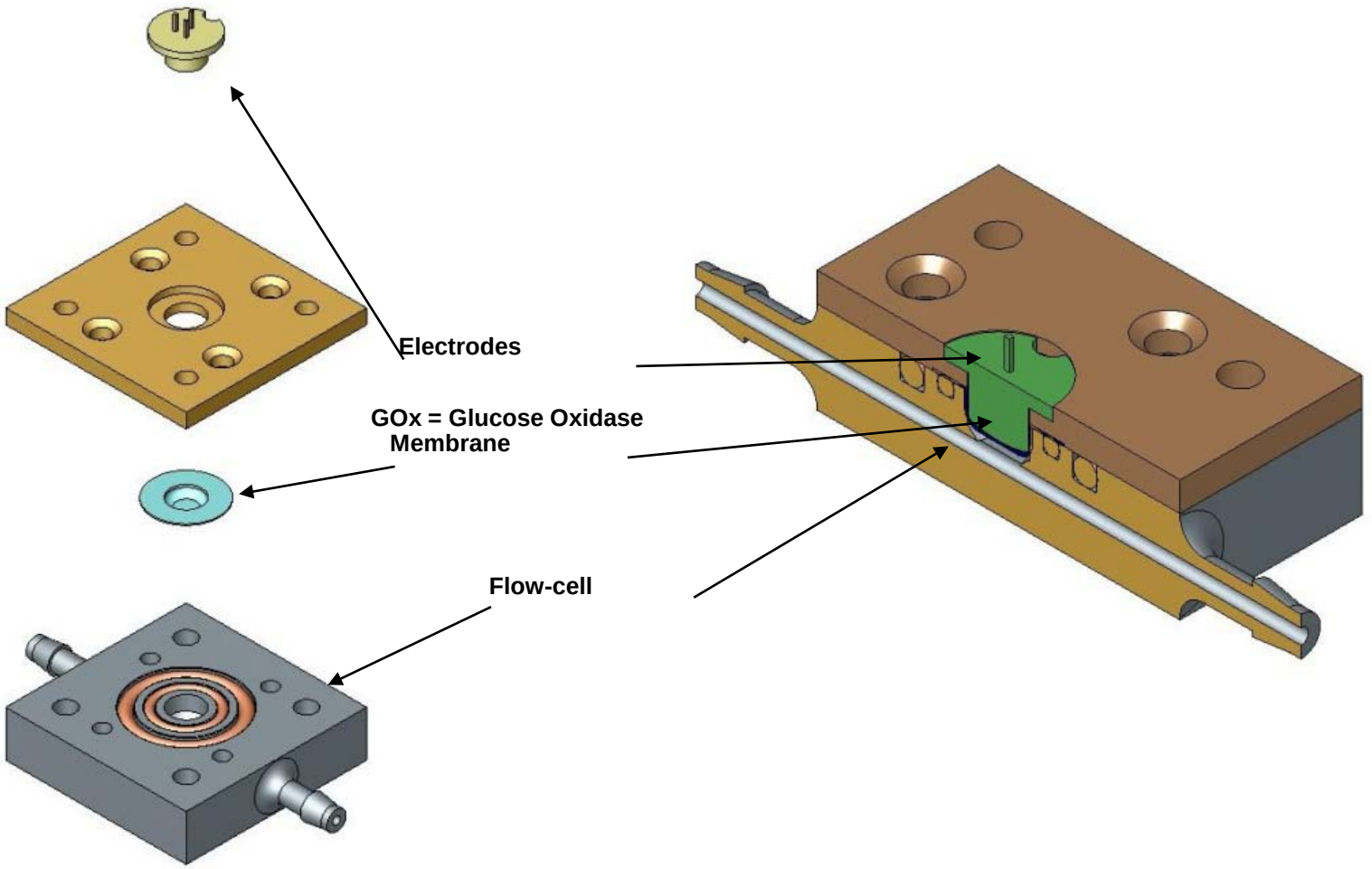
$$\text{Platinum anode:} \quad H_2O_2 \longrightarrow 2H^+ + 2e^- + O_2 \quad (2)$$

$$\text{Platinum cathode:} \quad 4H^+ + 4e^- + O_2 \longrightarrow 2H_2O \quad (3)$$

$$\text{Overall reaction:} \quad H_2O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O \quad (4)$$

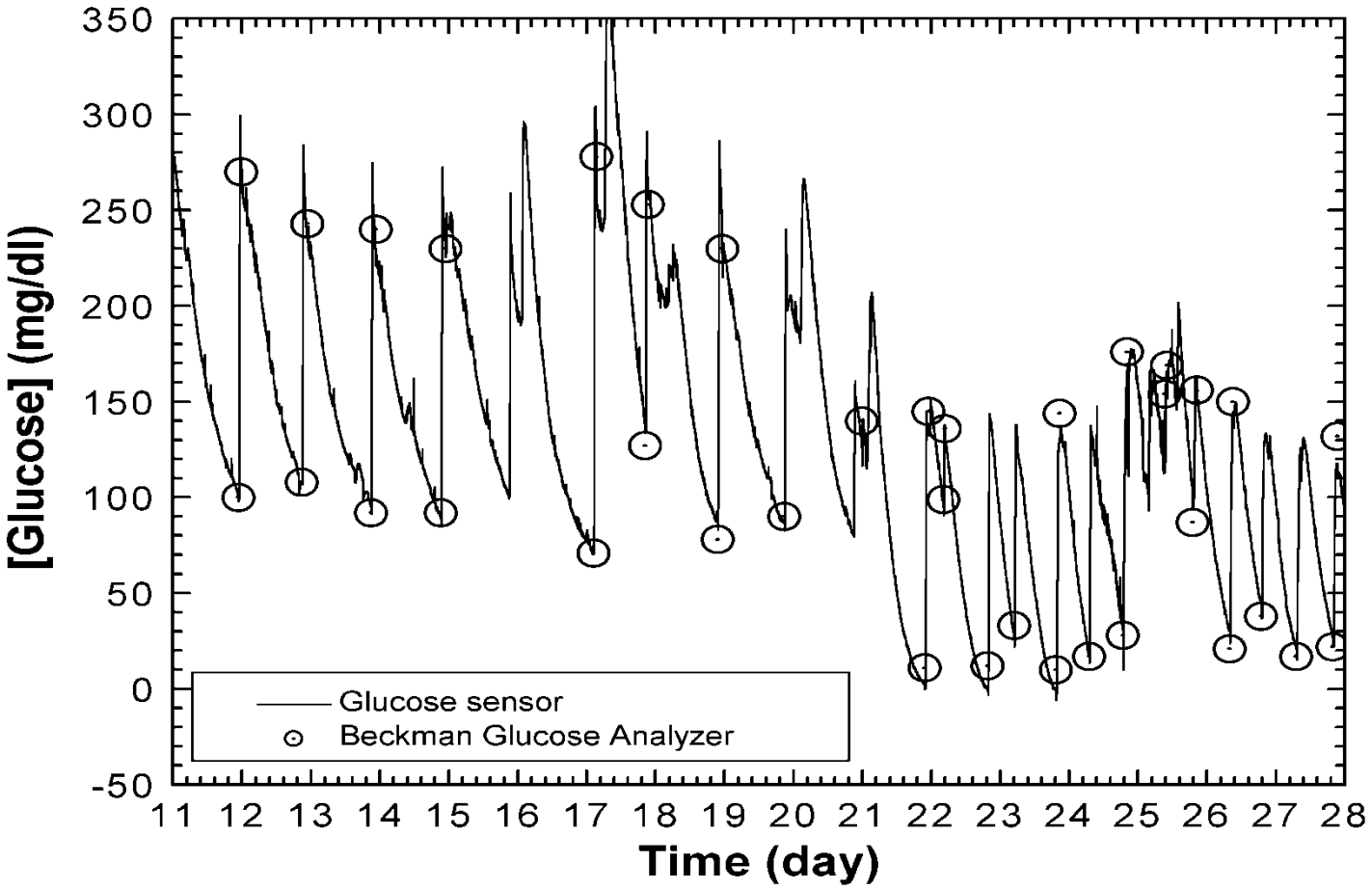
GOx : Glucose Oxidase

Glucose Sensor



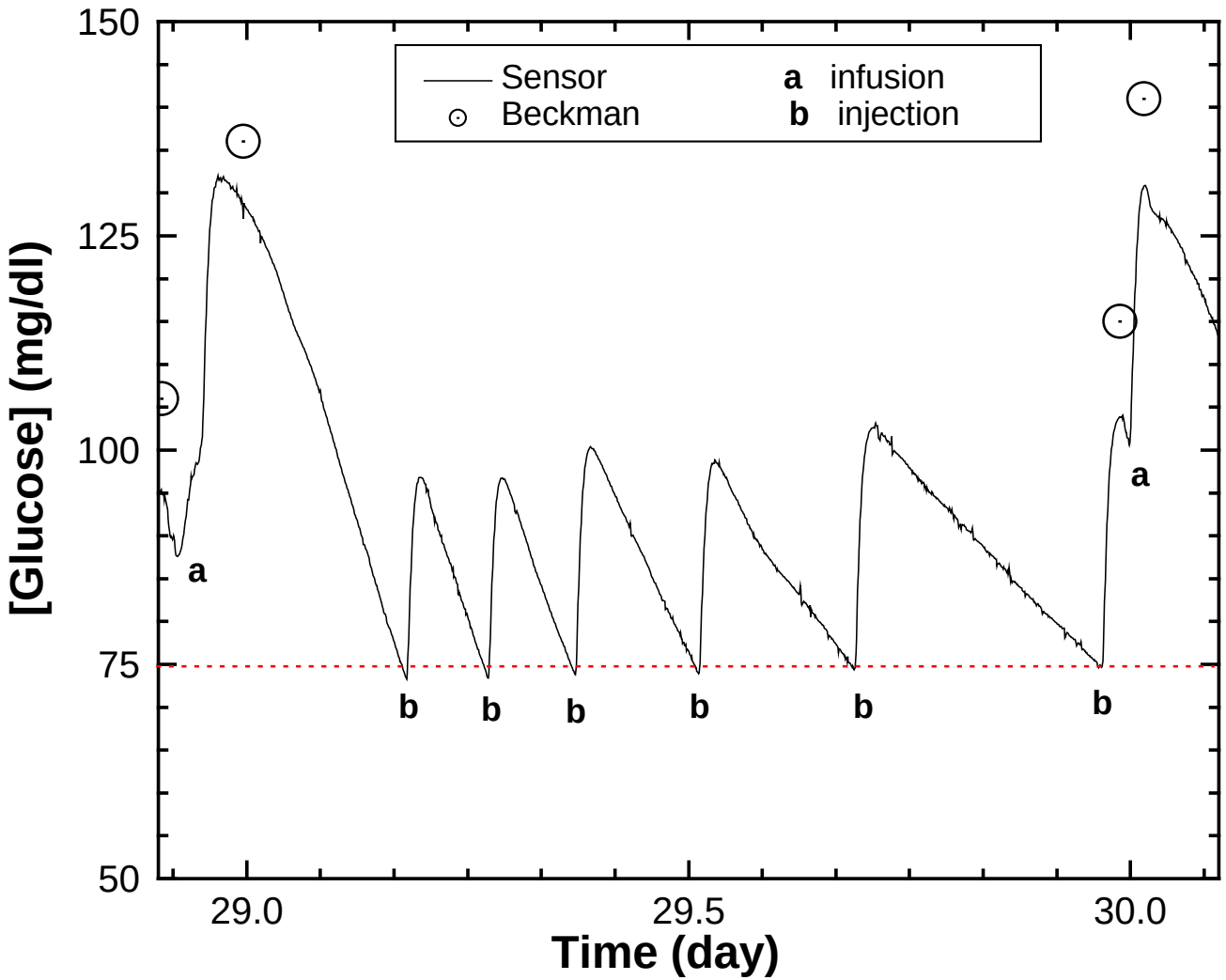
Y. Xu, A. S. Jeevaranjan, J. M. Fay, T. D. Taylor, M. M. Anderson. *J. Electrochem. Soc.*, **149**, H103-H106 (2002).

Plot of glucose concentration vs time in a Perfused bioreactor, where BHK-21 cells were fed once/twice a day

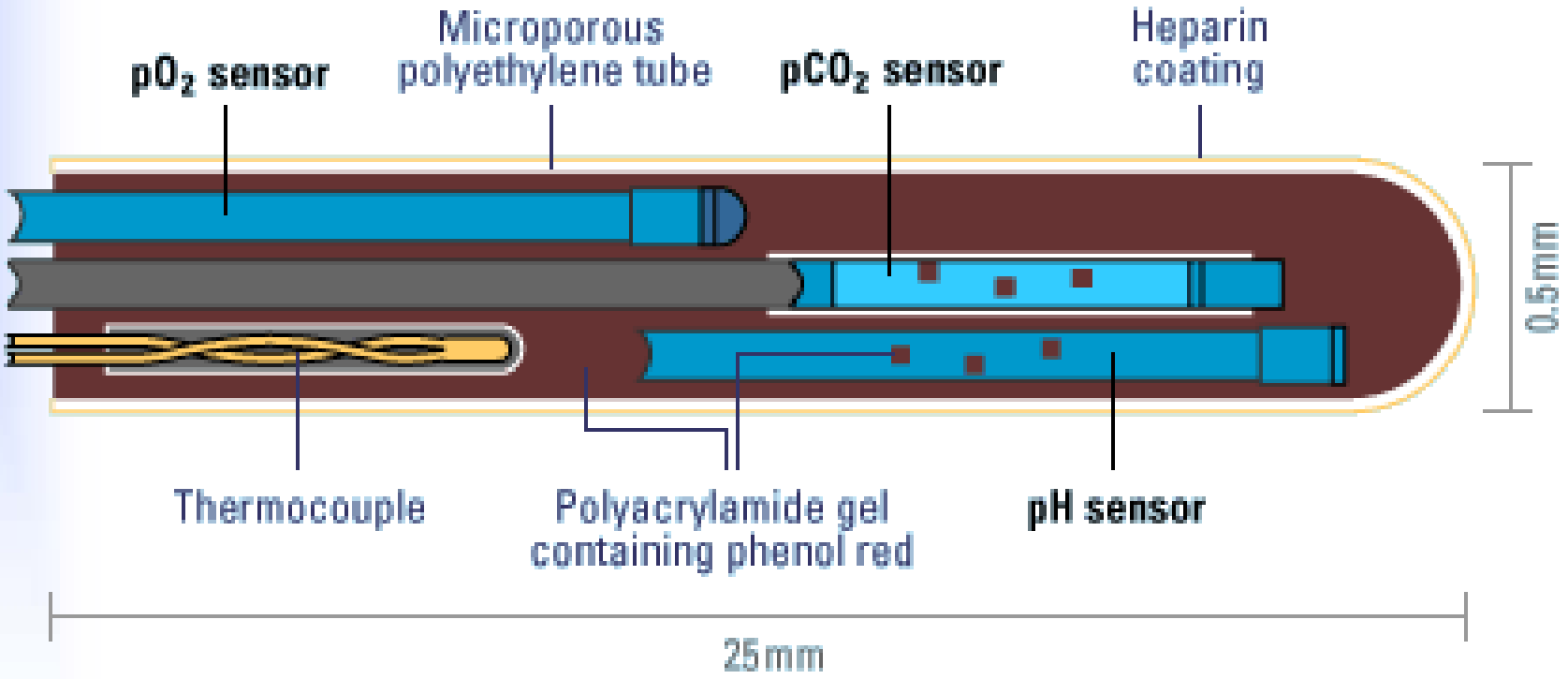


Y. Xu, G. Mathew, A. S. Jeevarajan and M. M. Anderson, *Biotech. and Bioeng.*, **87**, 473 (2004)

Performance of the Glucose Control (75 to 100 mg/dl) System



Cross section of a Paratrend sensor showing the three Optical fibers, pH, pCO_2, and pO_2, and a Thermocouple



Perfused Space Bioreactor



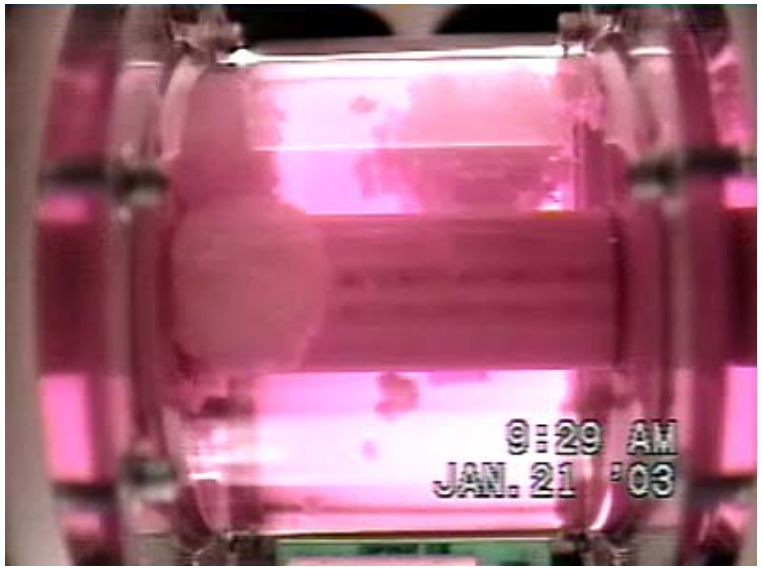
Power : 147 W; Volume : 1.86 cf; Dim : h 9.6”x w 17” x d 20”

STS-107 Results

GROUND



FLIGHT



- Bone stromal cells and prostate carcinoma co-culture
- On-orbit tissue aggregates spanned width of bioreactor

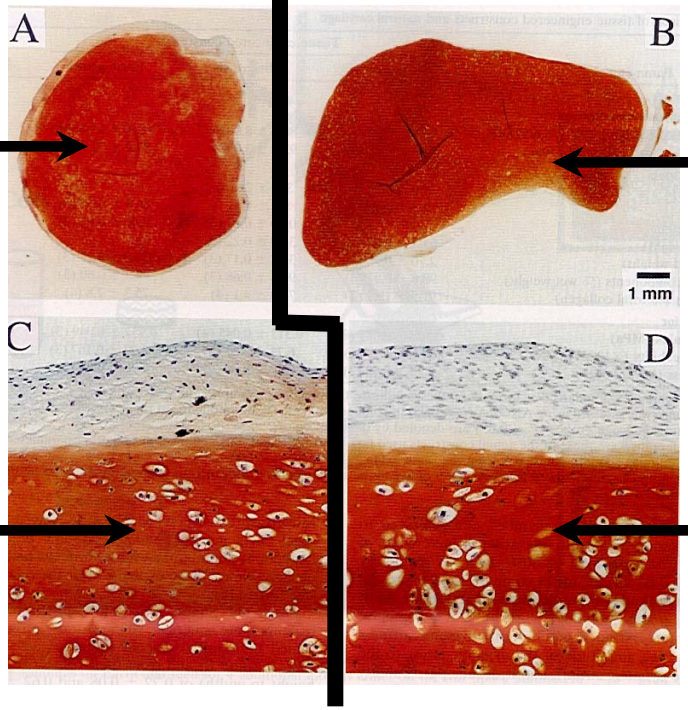
PI: Dr. Leland Chung, Emory University

Cartilage Growth in Bioreactors

NASA-Mir Bioreactor

Ground Based Bioreactor

Spherical
Less Dense
Immature
Cartilage



Disk shaped
More rigid
Cartilage

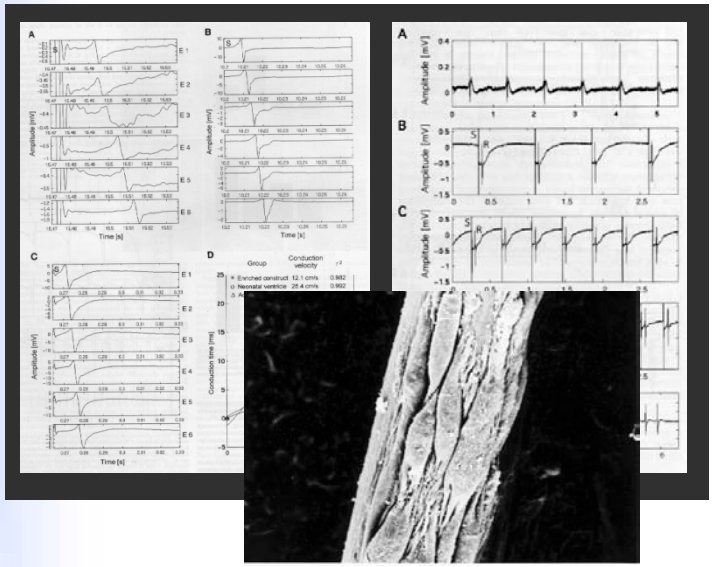
Mechanically weak but compressible

Mechanically stronger and less compressible

PI : L. Freed, MIT

More Rotating Bioreactor Results

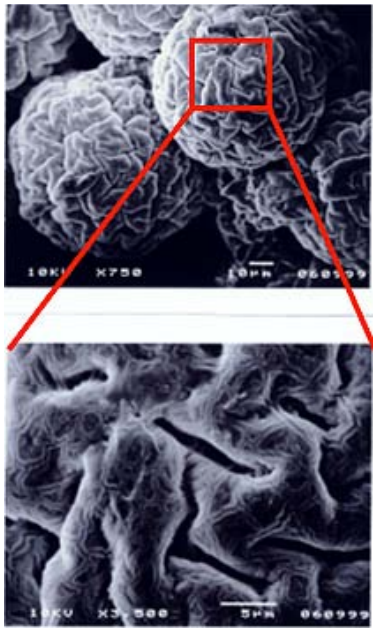
Heart muscle cells aligning and growing on connective tissue fiber



Propagation of difficult cells: first continuous cultures of Bowhead whale kidney cells

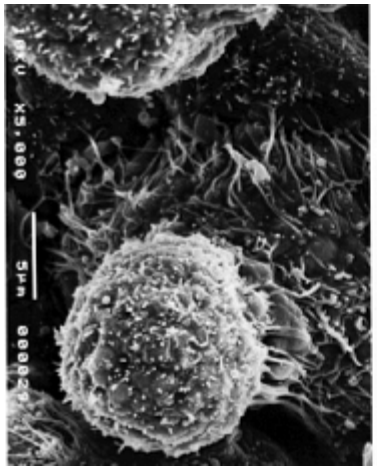
Investigate the response of mammals to environmental toxins in marine ecosystems.

(T. Goodwin, NASA/JSC)



Liver Tissue: Cellular shape and arrangement enabling investigation of infection in a more native tissue model

Hepatitis virus pathogenesis model
Drug metabolism (StelSys, LLC)
Toxicology testing
Extracorporeal liver support technology (StelSys, LLC)





Bioreactor Research – Applications to NASA/Human Health on Earth

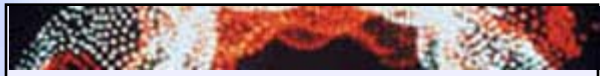


INFECTIOUS DISEASES

• Established the NASA/NIH Center for Three Dimensional Tissue Culture which provides researchers bioreactors and an opportunity to develop new model systems for diseases whose pathology cannot be reproduced by merely growing the right cells in monolayer culture.

- Human Immunodeficiency Virus (HIV)
- Ebola viral transmittal
- Borrelia, the etiologic agent of Lyme disease
- Norwalk virus

• Model for Salmonella pathology in engineered colon tissue



DRUG EFFICACY

• Facilitating testing of drugs to determine their safety without using animals and reducing the need to use human volunteers in final testing

• Bio-production of an enzyme that HIV needs to reproduce, analysis of enzyme structure, and designer drugs to inhibit the HIV virus

• Studying human metabolism of drugs

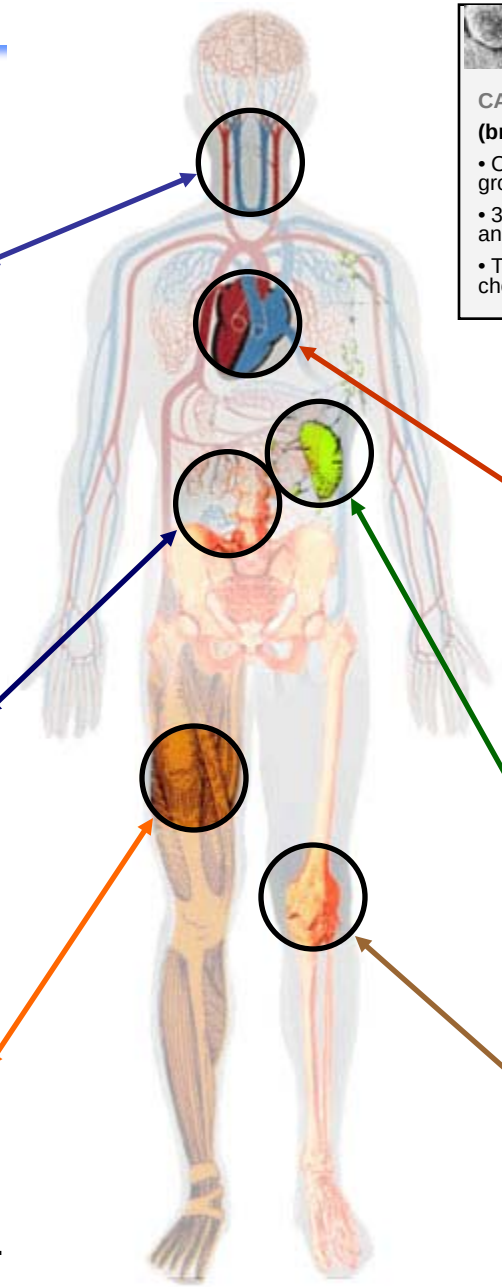


ACUTE INJURY AND RECONSTRUCTIVE SURGERY

• Biodegradable scaffolds to grow cartilage cells needed for reconstructive surgery

• Models and transplantable cartilage tissues that could revolutionize treatment for joint diseases and injuries

• Cytokine synthesis in analog culture to address wound healing





CANCER

(breast, skin, prostate, ovary, bone and colon)

• Co-culture of cancer and somatic cells to understand cancer growth and human immune system response

• 3D tumor disease models for studies in proliferation, signaling, an apoptosis

• Testing three-dimensional tissues for sensitivity to chemotherapy and hormonal therapy



HEART DISEASE

• Engineered heart tissue for research in drug testing, and the eventual growth of transplantable heart tissue

• Studying how heart cells interact to form cardiac structures outside the body



DIABETES

• Working on pancreatic tissue for transplantation

•Cultivating and transplanting beta cells into Type I diabetics



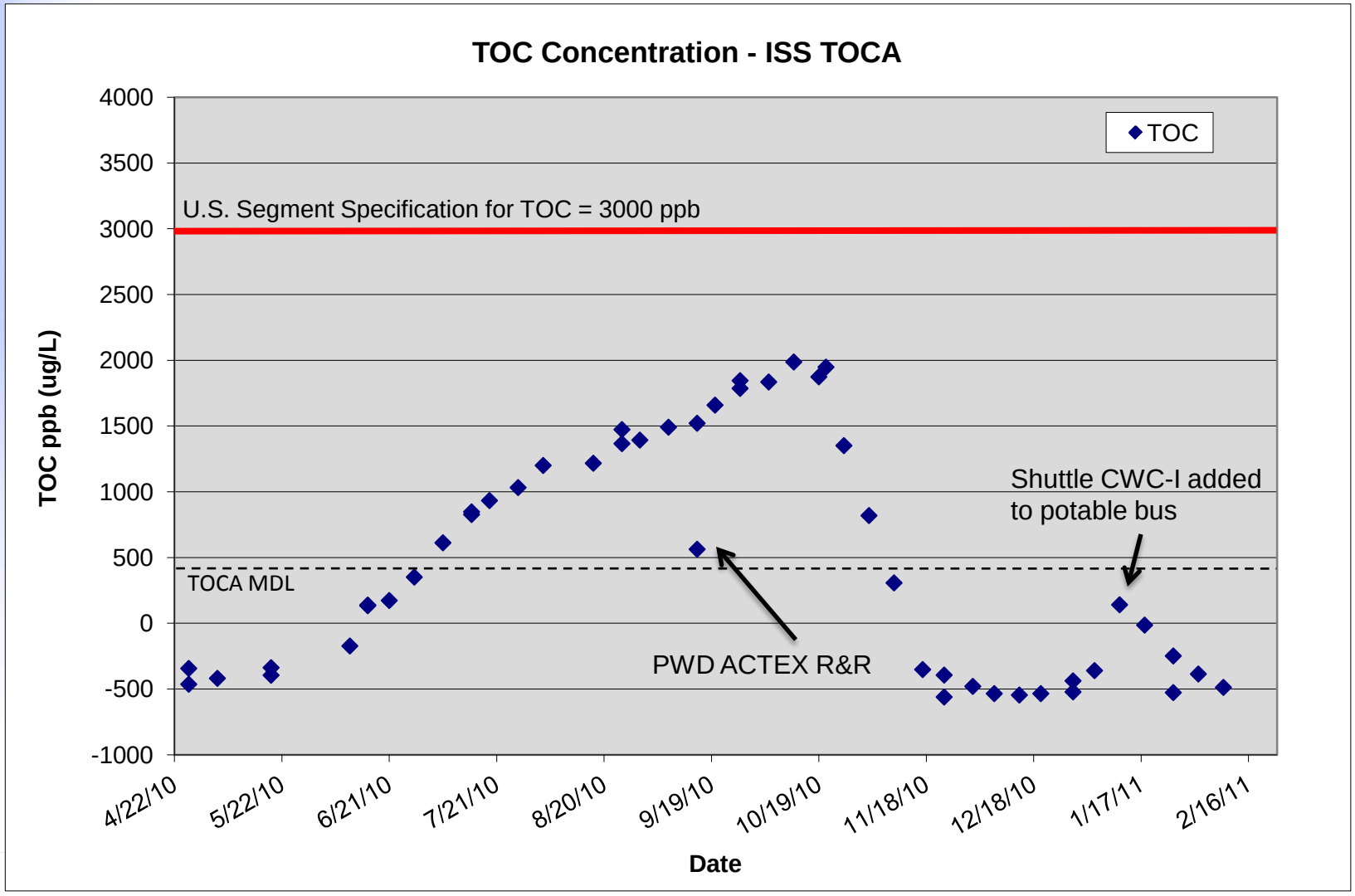
BONE LOSS

• Mechanisms involved in bone loss related to microgravity

• Optimal characteristics of micro-beads for growing bone tissue

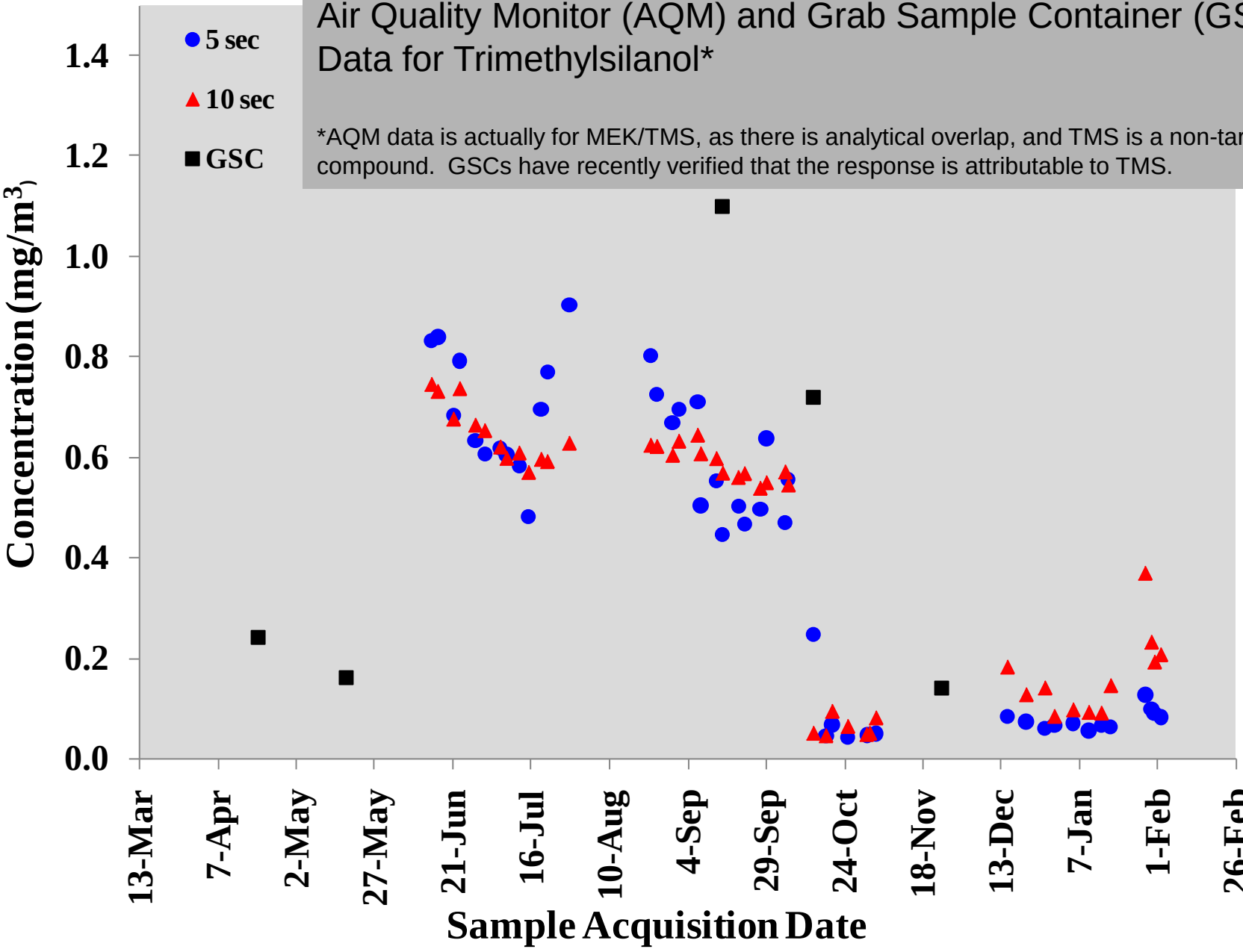
A.

TOCA Data Summary



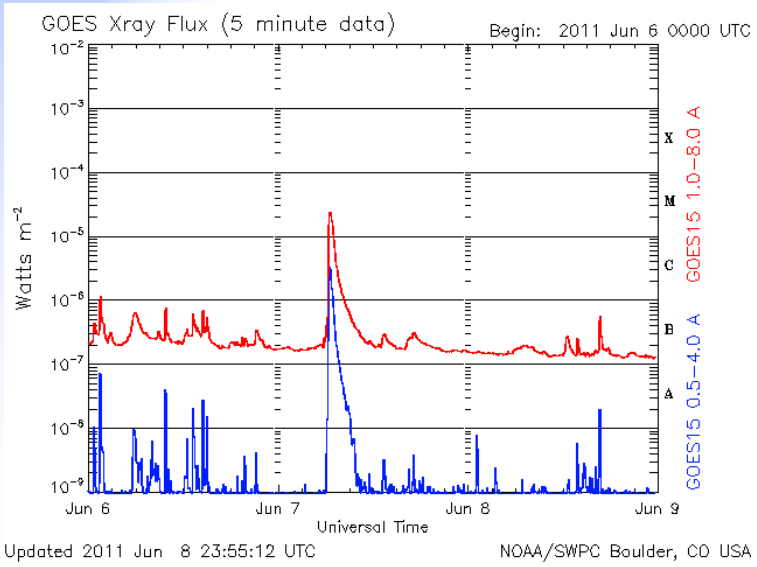
Air Quality Monitor (AQM) and Grab Sample Container (GSC) Data for Trimethylsilanol*

*AQM data is actually for MEK/TMS, as there is analytical overlap, and TMS is a non-target compound. GSCs have recently verified that the response is attributable to TMS.



June 7, 06:16 GMT (01:16 CDT)

- M2.5 flare
- Coronal Mass Ejection (CME)



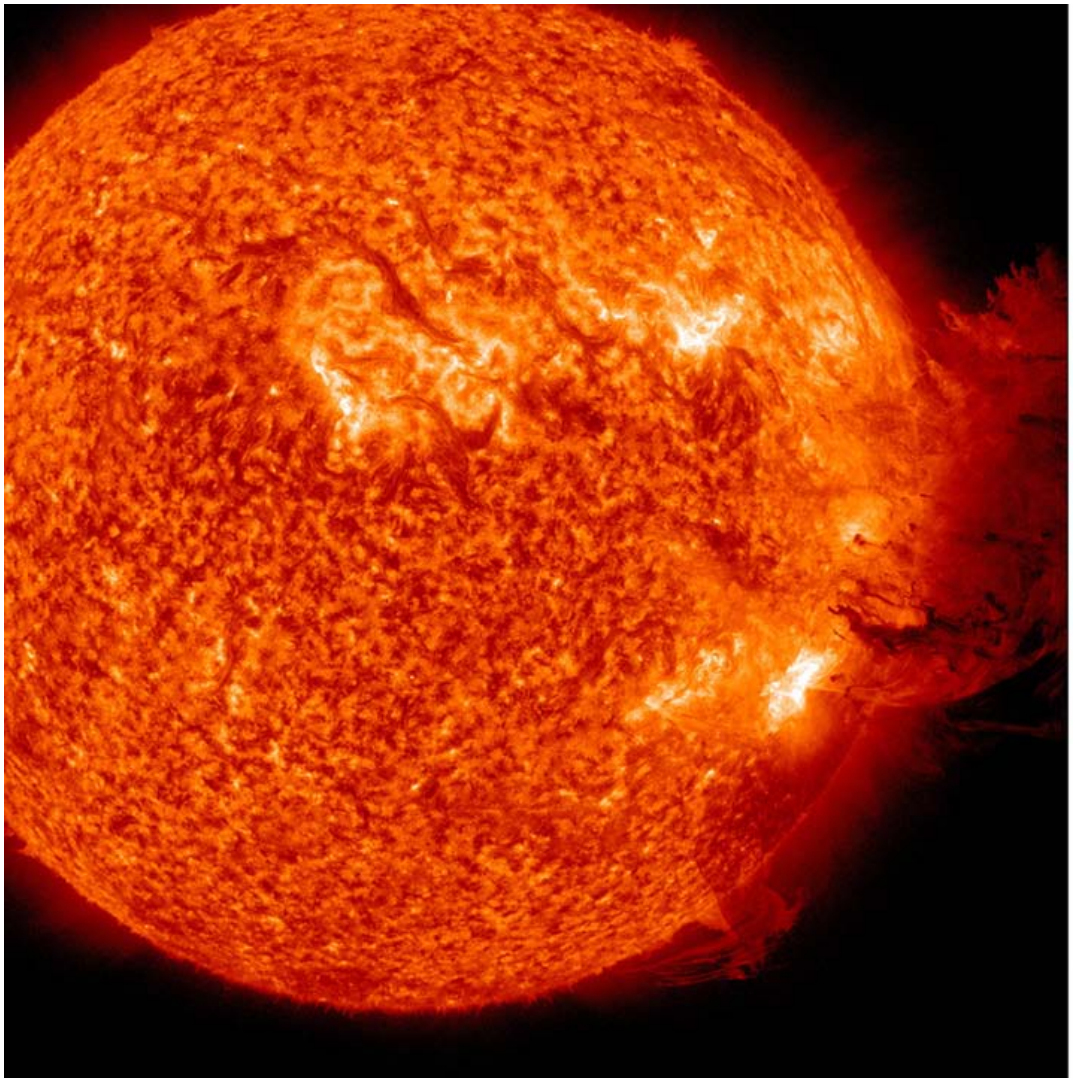
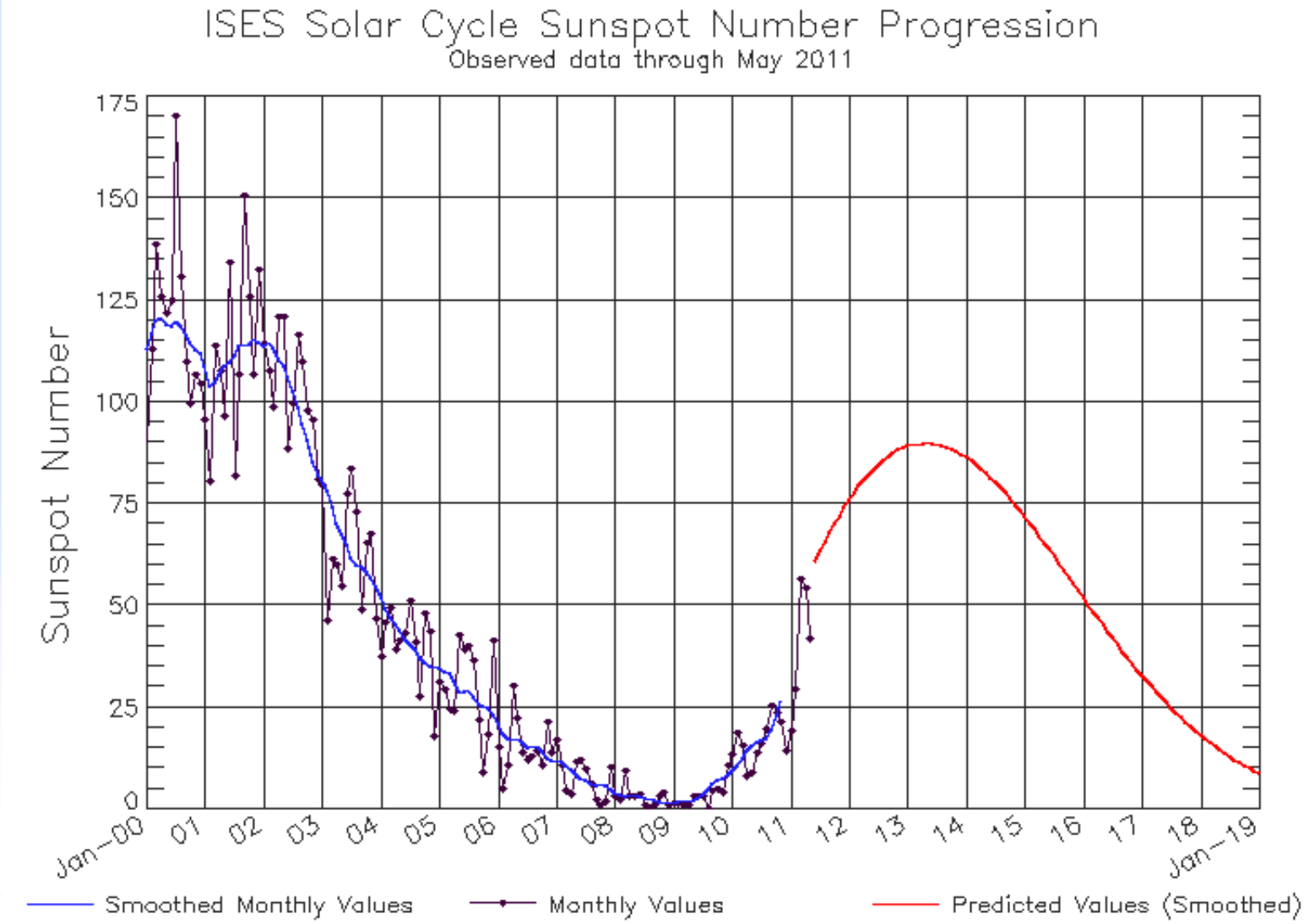


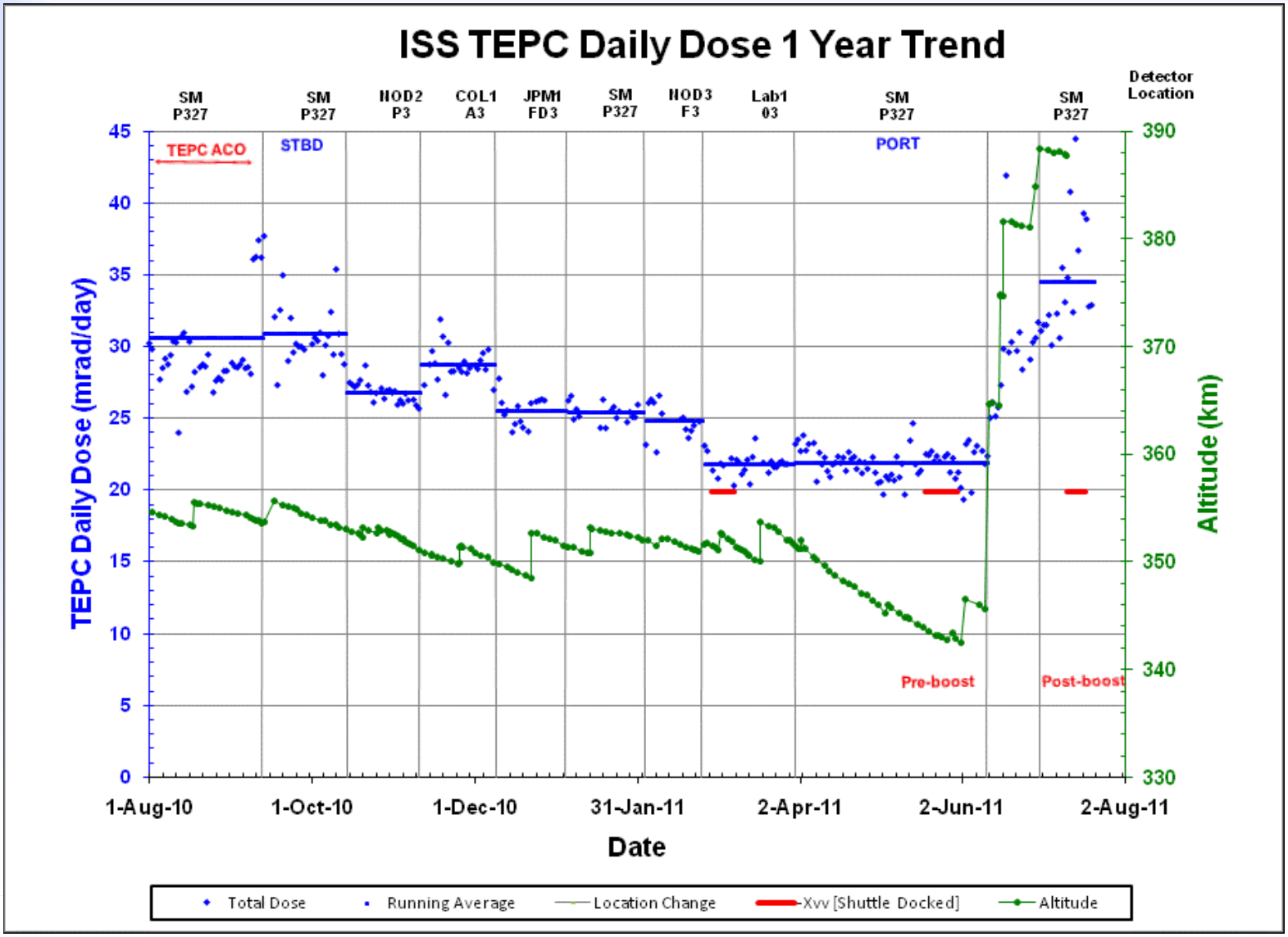
Image from http://sdo.gsfc.nasa.gov

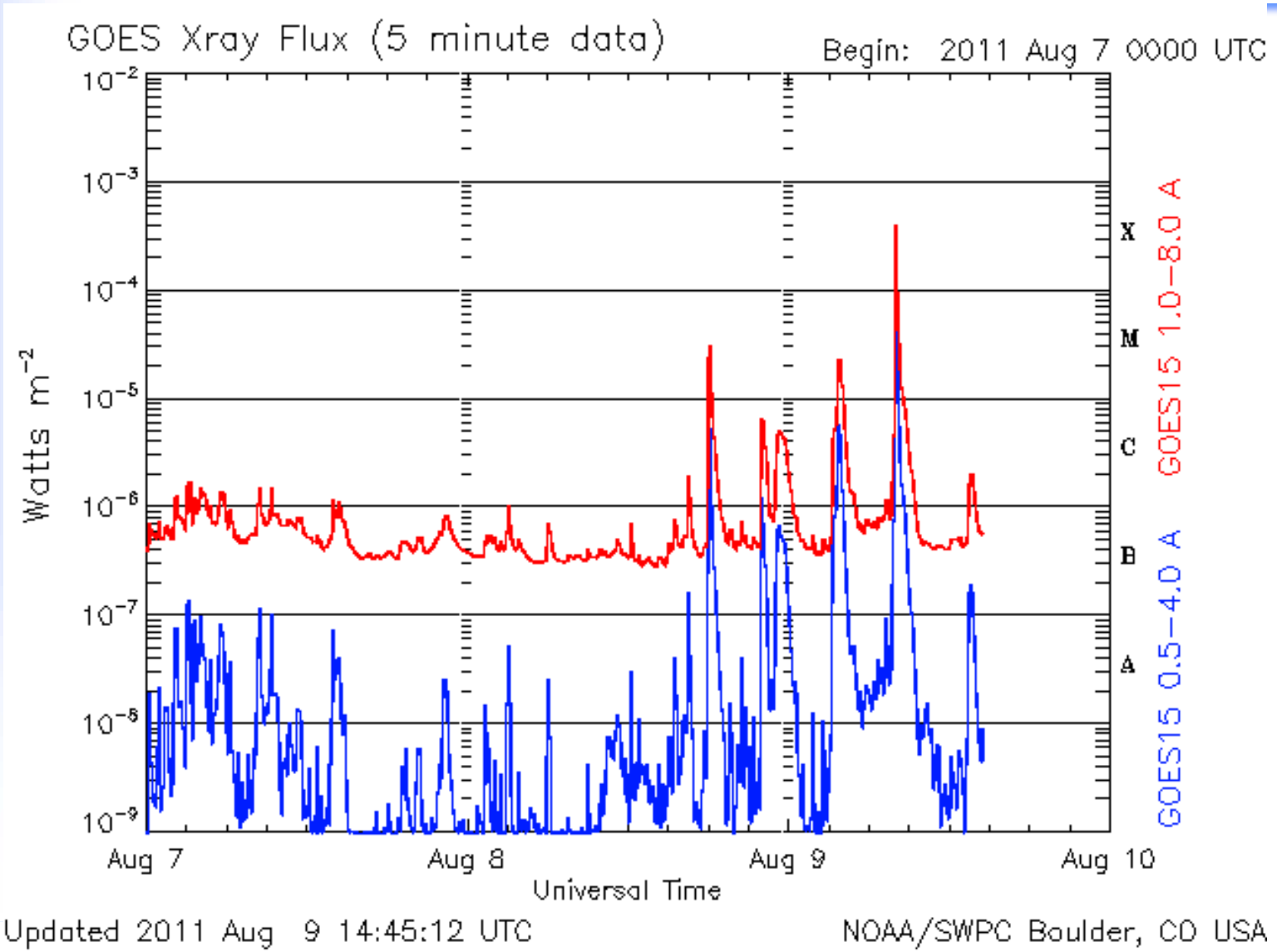
Solar Maximum is Approaching



Energetic Solar Particle Event

- GMT 221; ISS 27/28
- Energetic Solar Particle Event (ESPE)
- An Energetic Solar Particle Event (>100MeV proton levels exceeded 1 particle flux unit) began at 08:25GMT. This increases the radiation dose rates at high geomagnetic latitudes. The vehicle made its first pass through one of these regions of enhanced radiation at 09:05GMT. Radiation environment levels meet Alert Condition criteria per Flight Rule B14-7. Proton levels are above thresholds, however, no crew action is required.
-
- Upcoming high dose rate passes will occur at the following GMT times:
-
- In Out Duration (minutes)
- 9:53 9:59 6
- 10:41 10:43 2


ISS TEPC Daily Dose 1 Year Trend
Detector Location
SM P327
SM P327
NOD2 P3
COL1 A3
JPM1 FD3
SM P327
NOD3 F3
Lab1 03
SM P327
SM P327
TEPC ACO
STBD
PORT
Pre-boost
Post-boost
TEPC Daily Dose (mrad/day)
Altitude (km)
0
5
10
15
20
25
30
35
40
45
330
340
350
360
370
380
390
1-Aug-10
1-Oct-10
1-Dec-10
31-Jan-11
2-Apr-11
2-Jun-11
2-Aug-11
Date
Total Dose
Running Average
Location Change
Xvv [Shuttle Docked]
Altitude

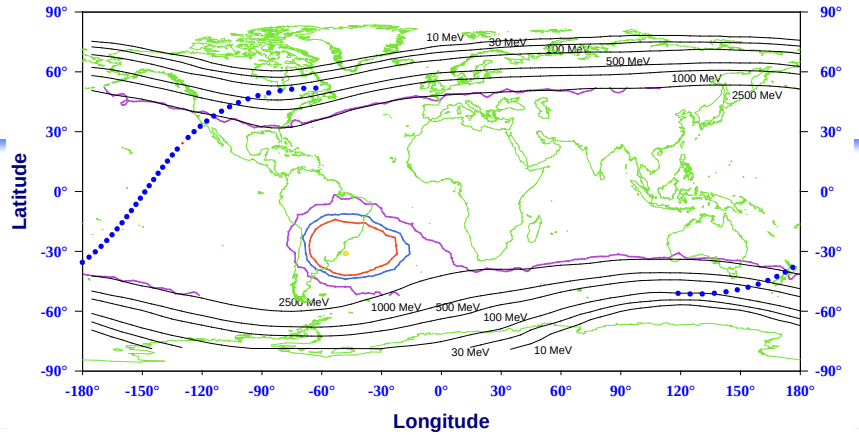

GOES Xray Flux (5 minute data)
Begin: 2011 Aug 7 0000 UTC
Watts m-2
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
X
M
C
B
A
GOES15 1.0-8.0 A
GOES15 0.5-4.0 A
Aug 7
Aug 8
Aug 9
Aug 10
Universal Time
Updated 2011 Aug 9 14:45:12 UTC
NOAA/SWPC Boulder, CO USA

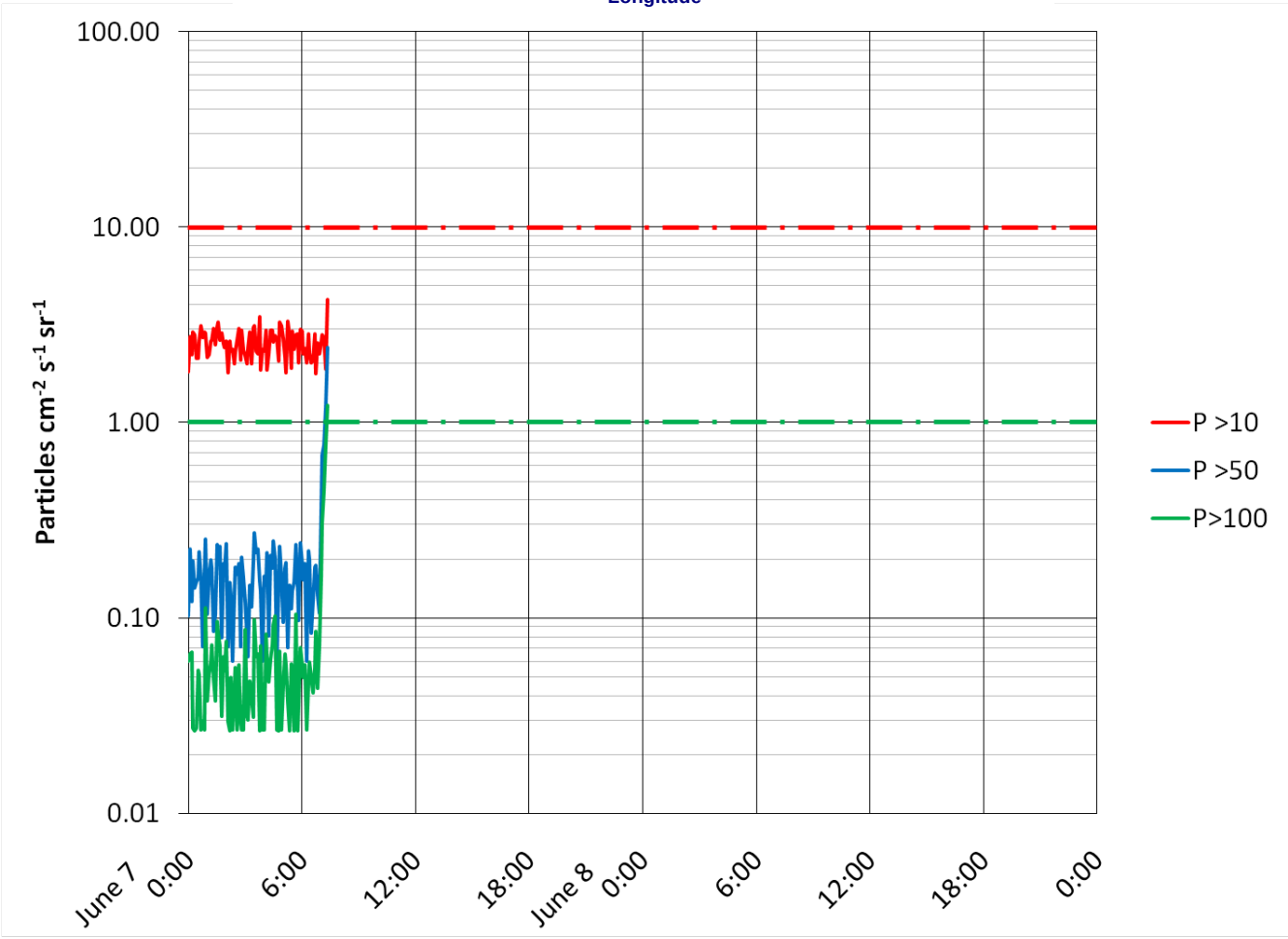
Tibbitt Lake, Canada, Aug 2, 2011



07:20 GMT (02:20 CDT)

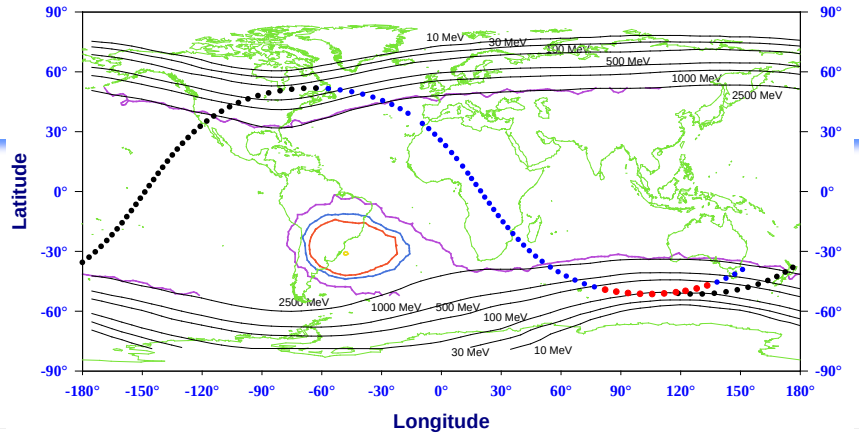
- EPSE started
- Reported to console
- Notified FCT
- Distributed Alerts
- Ran dose models

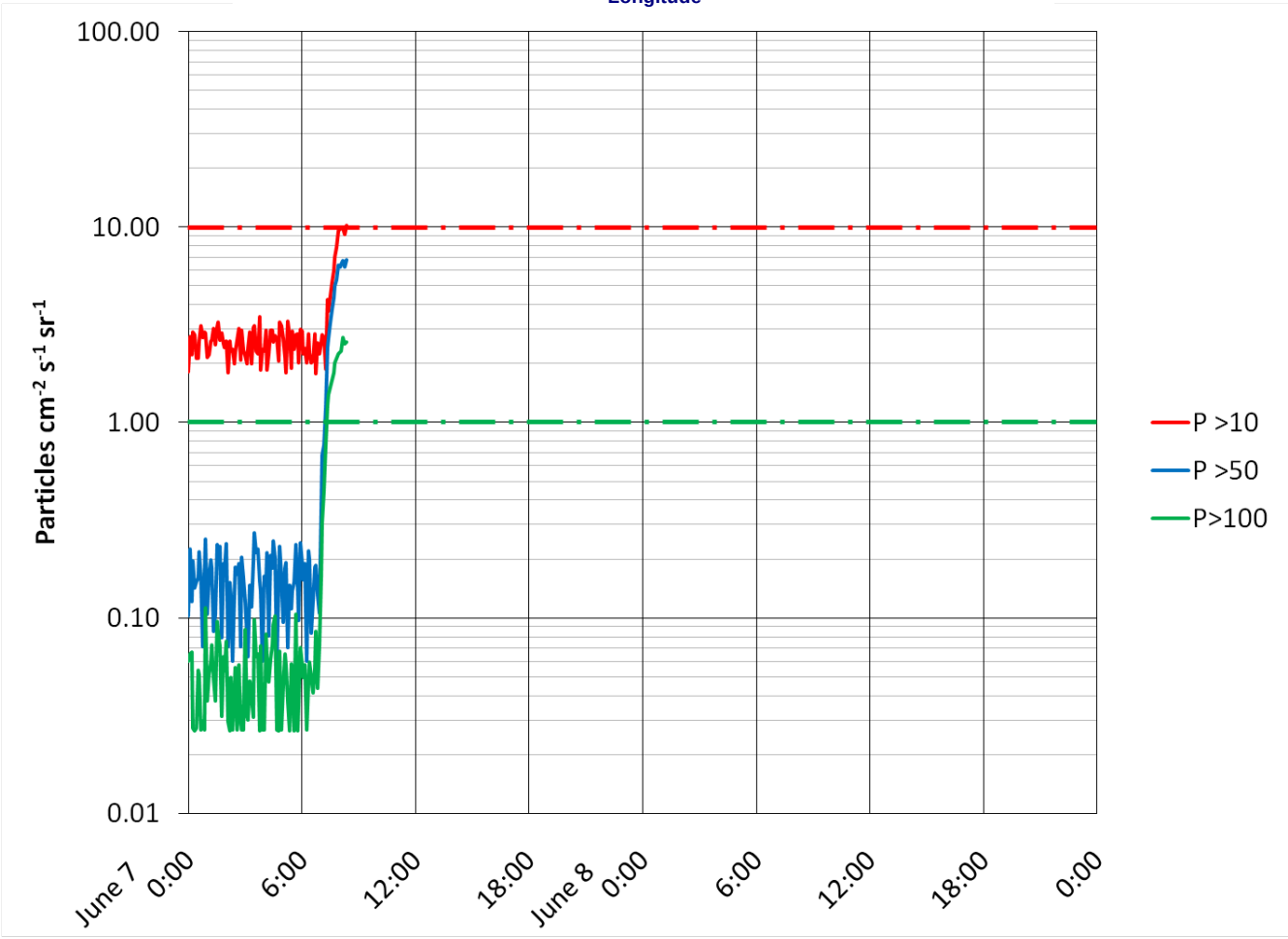




08:15 GMT (03:15 CDT)

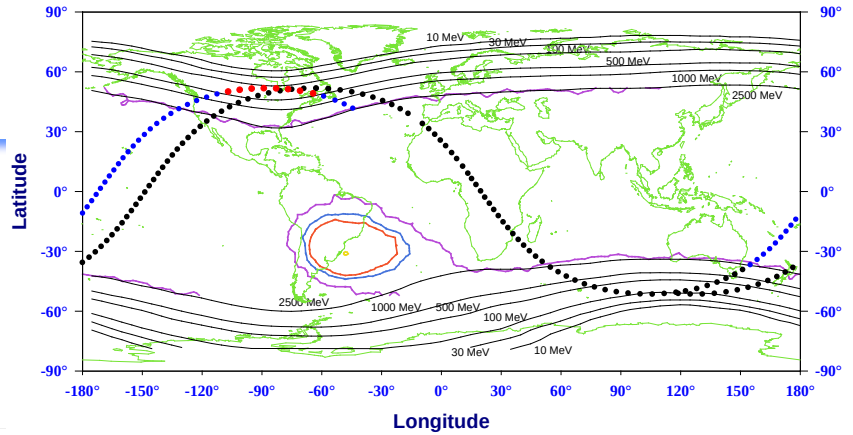
- SPE started
- Submitted Flight Note
- Completed Pass 1

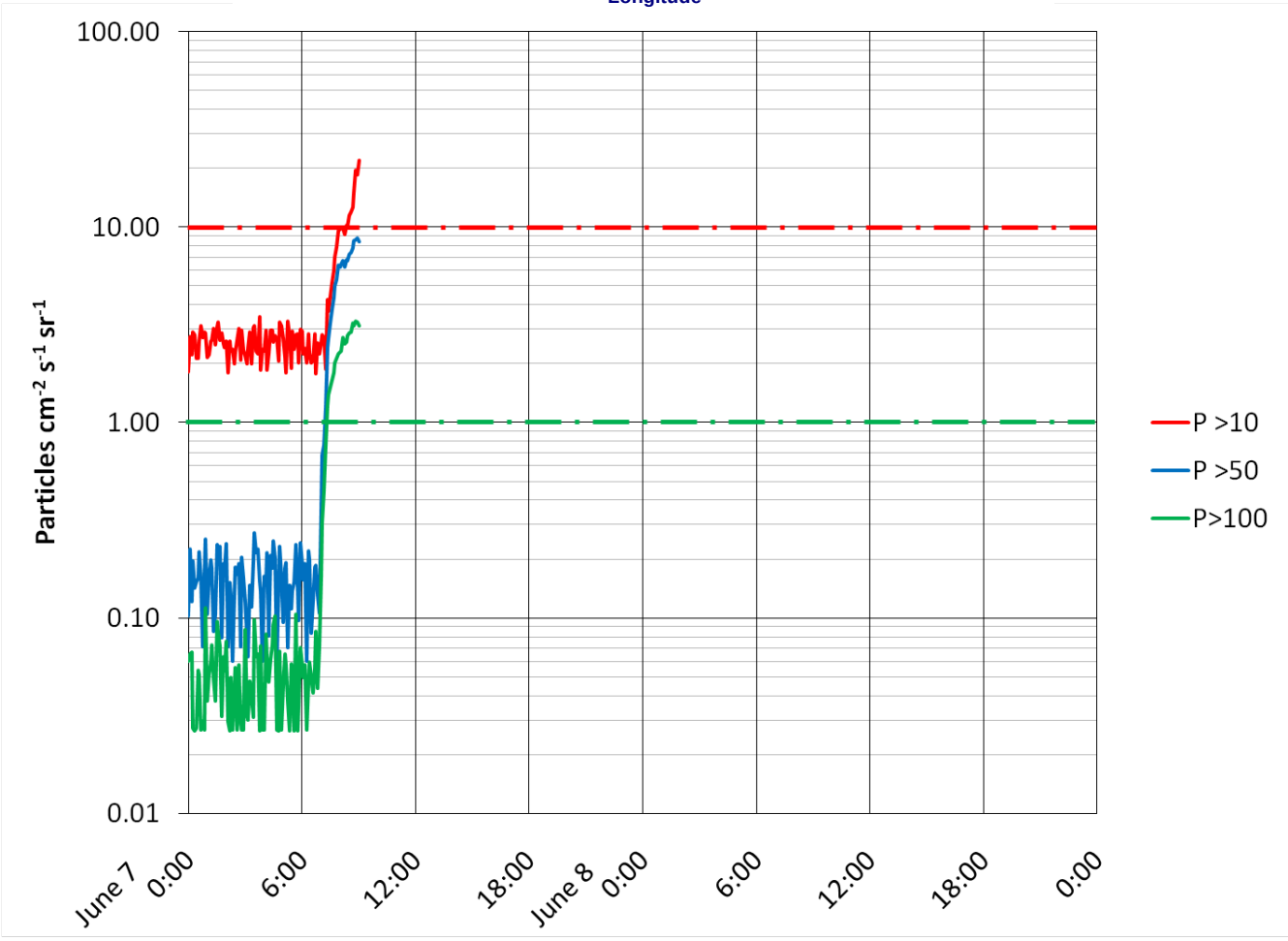




09:00 GMT (04:00 CDT)

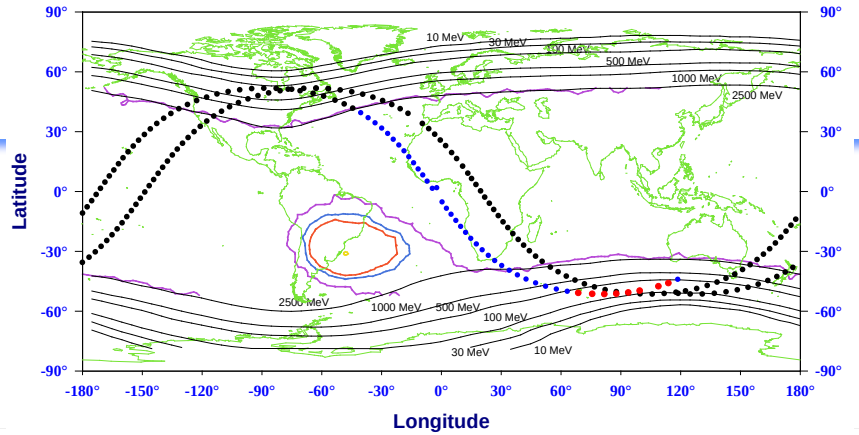
- Completed Pass 2
- NOAA contact
- Updated FCT
- Redistributed Alert
- BME called Surgeon

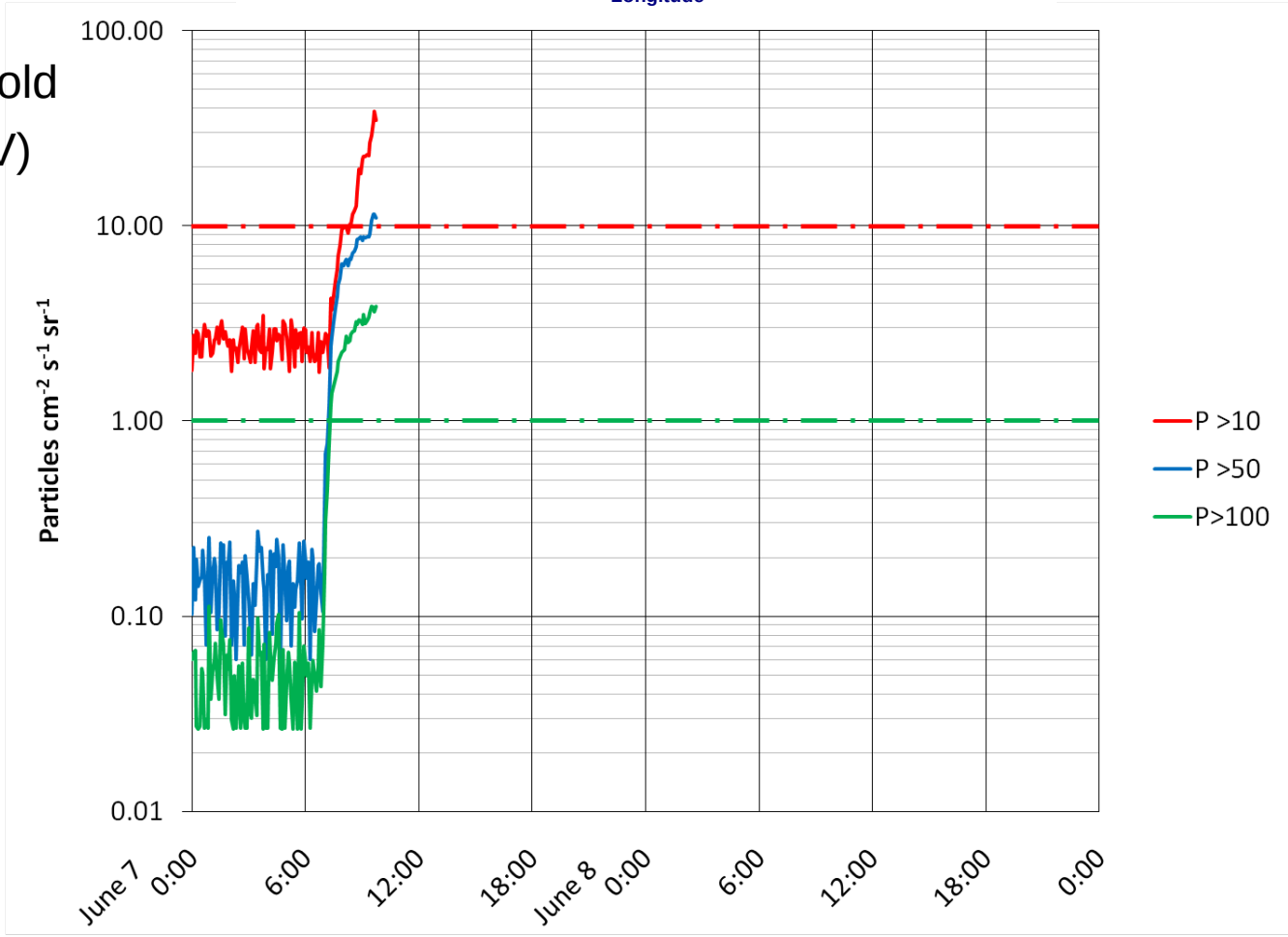




09:45 GMT (04:45 CDT)

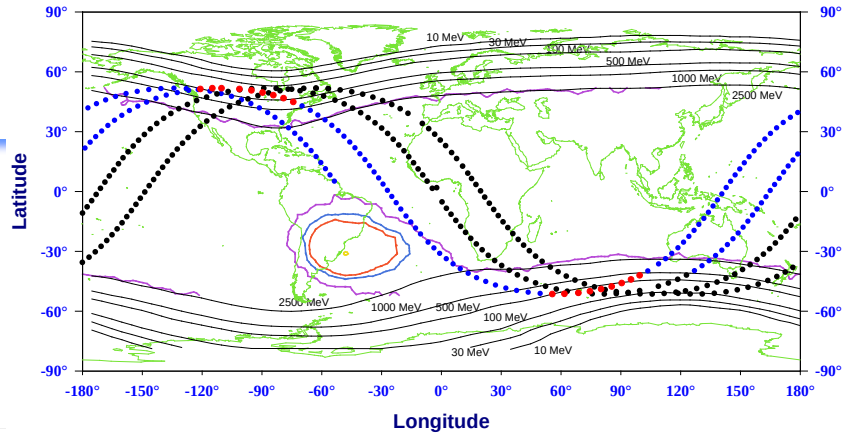
- Completed Pass 3
- Crossed P>50 threshold
- Contacted Flight (ATV)
- Surgeon contact (Soyuz)

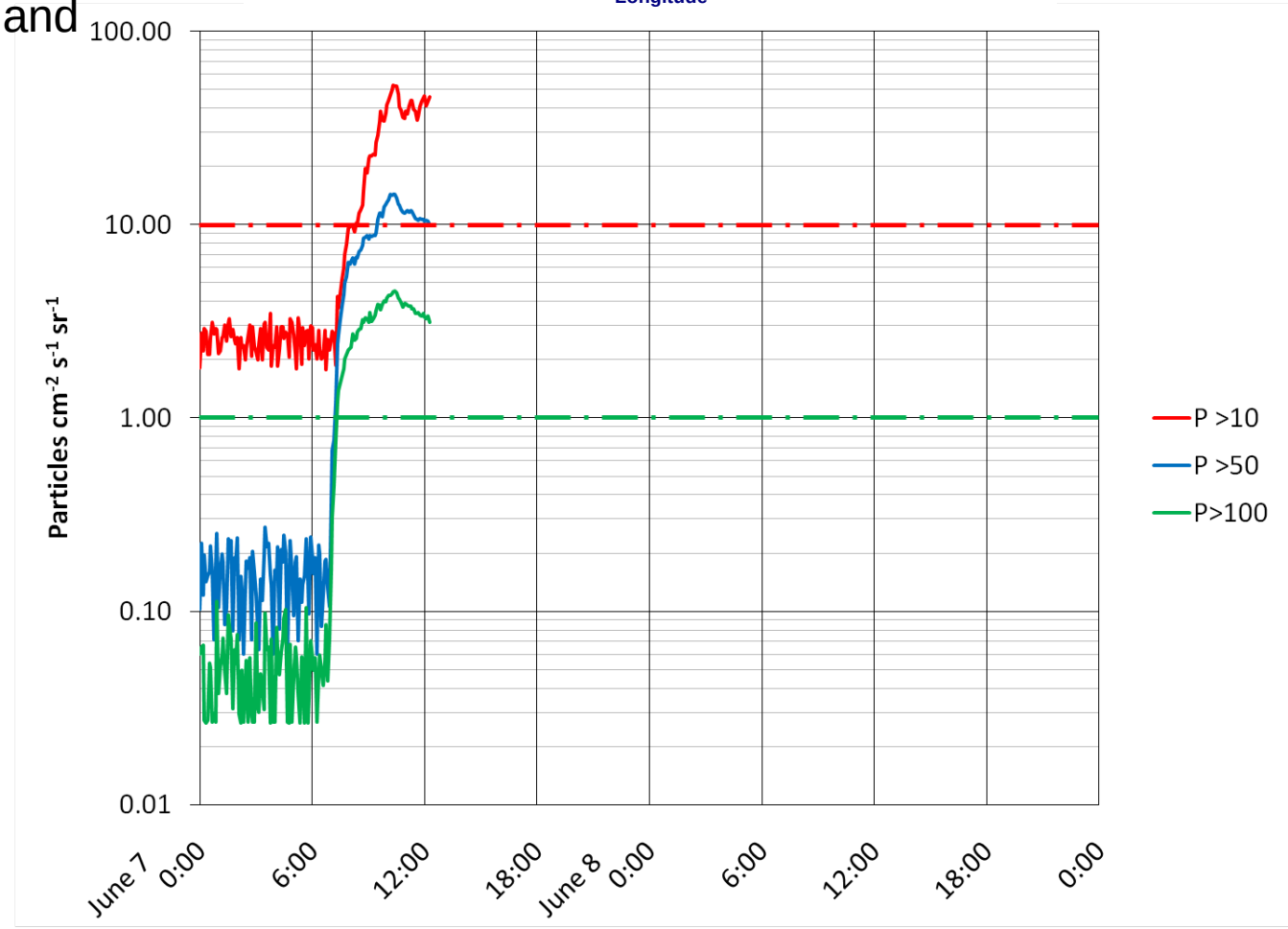




12:15 GMT (07:15 CDT)

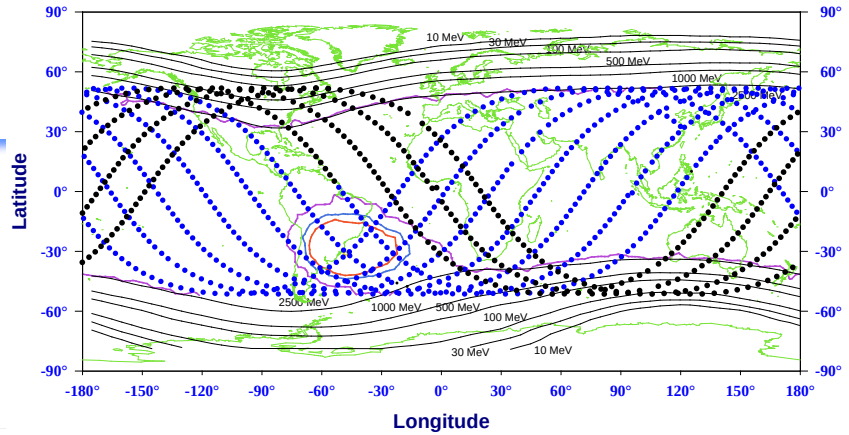
- Completed Passes 4 and 5
- Discussed Soyuz docking with Flight Director

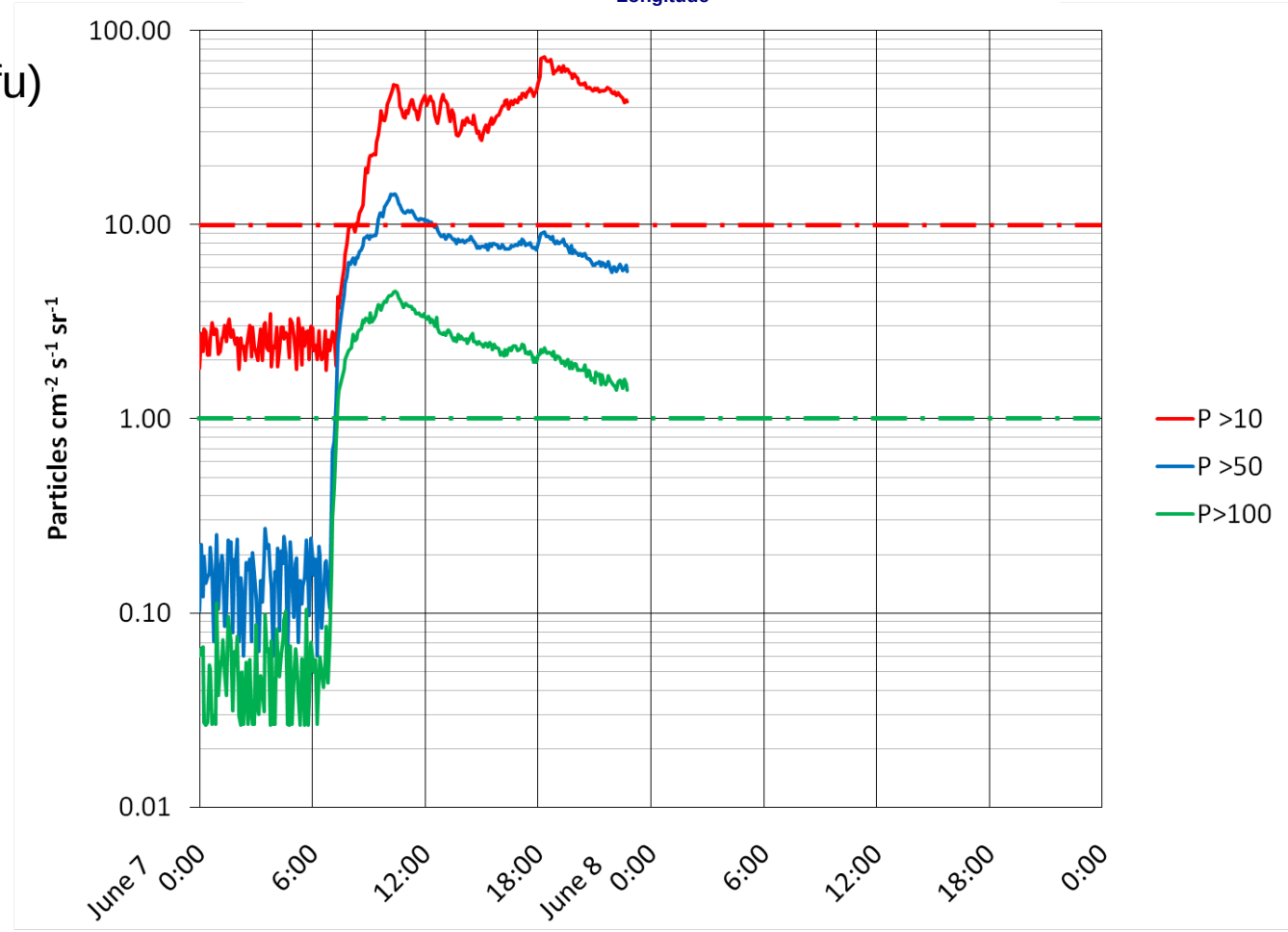




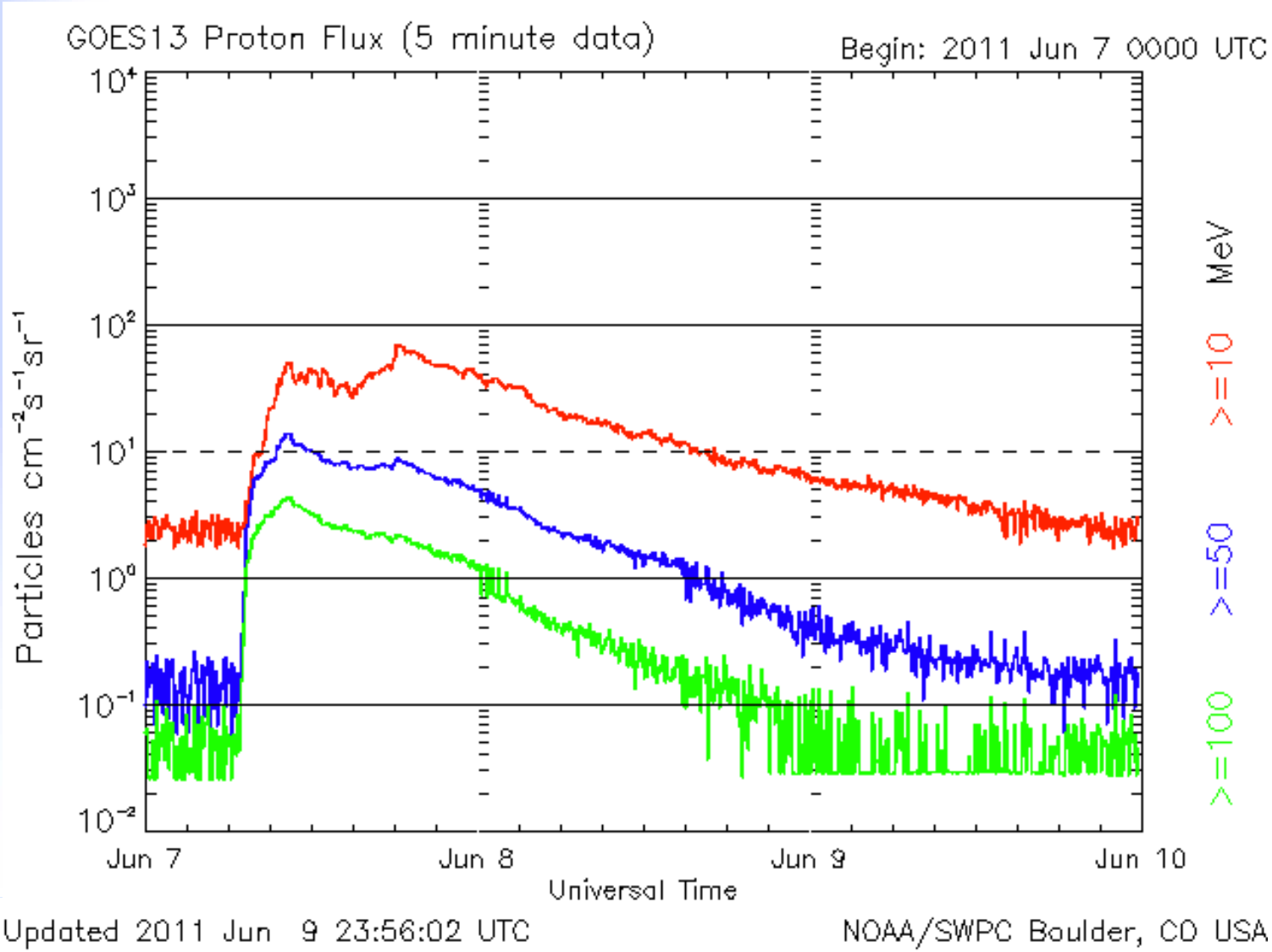
22:45 GMT (17:45 CDT)

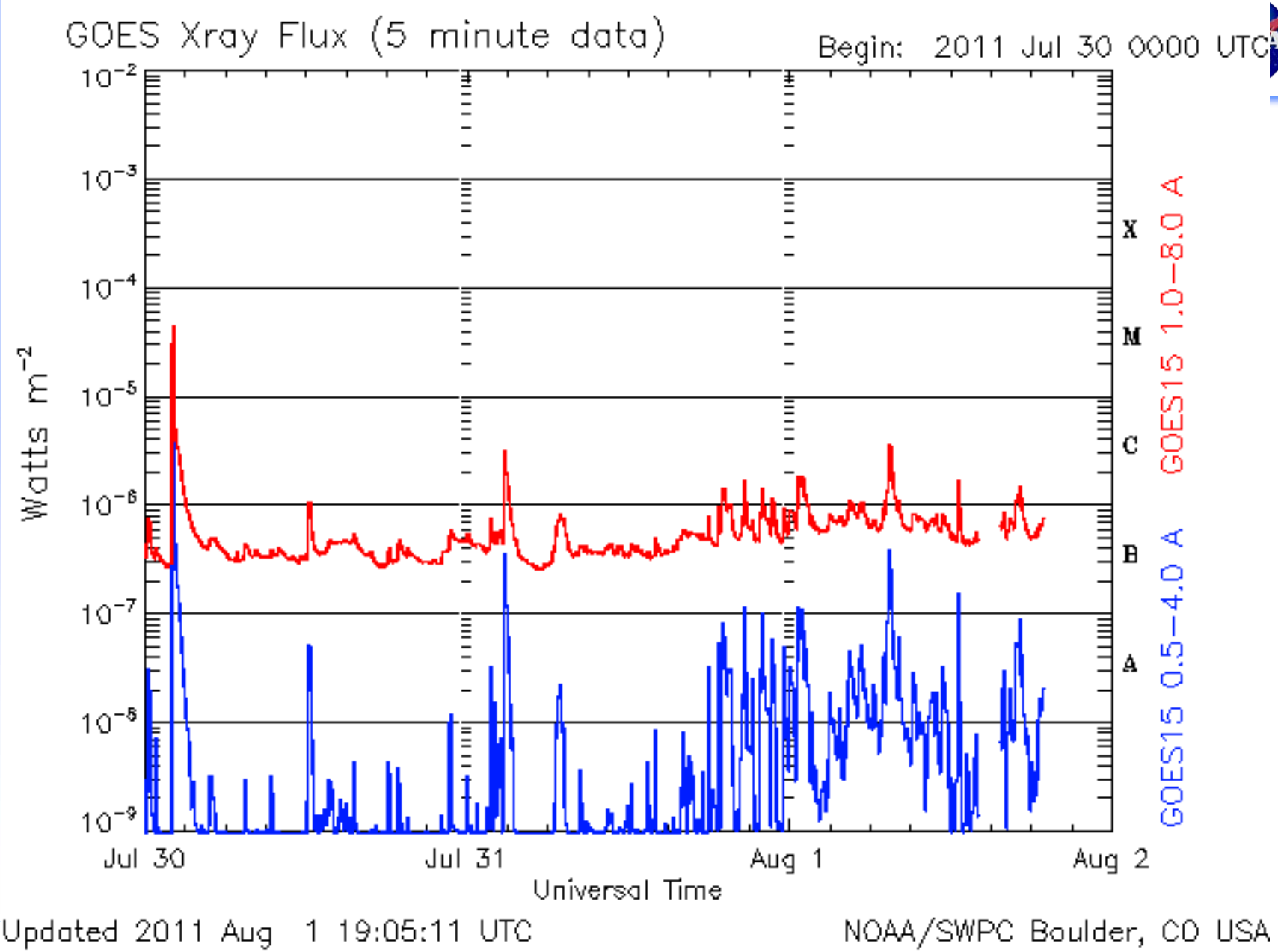
- Soyuz launched
- ESPE closed (1.43 pfu)
- Ended contingency support





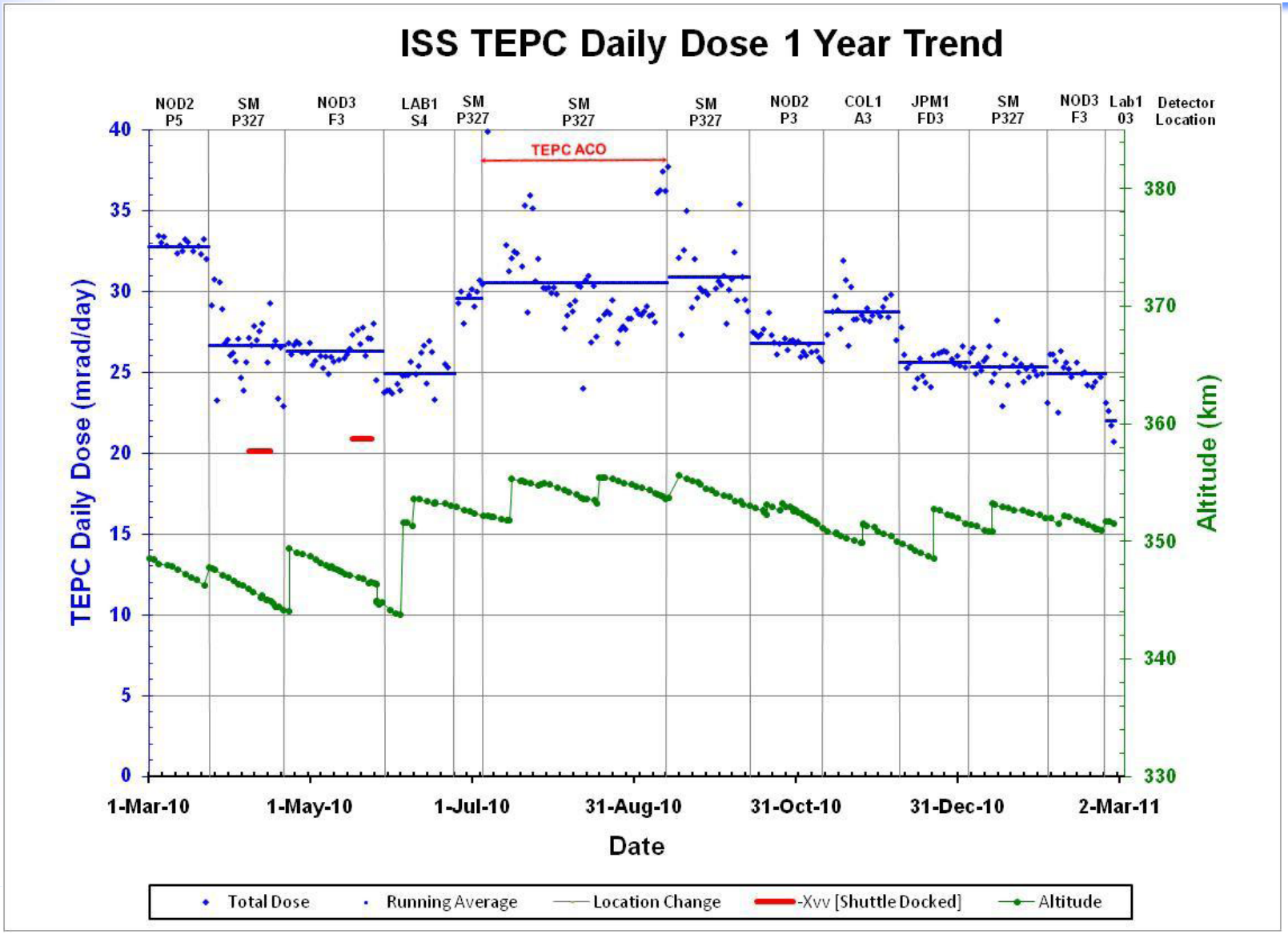
Solar Particle Event





Aurora Video:http://www.youtube.com/ytakasaka

Ref: Spaceweather.com


ISS TEPC Daily Dose 1 Year Trend
NOD2 P5
SM P327
NOD3 F3
LAB1 S4
SM P327
SM P327
SM P327
NOD2 P3
COL1 A3
JPM1 FD3
SM P327
NOD3 F3
Lab1 03
Detector Location
TEPC ACO
TEPC Daily Dose (mrad/day)
Altitude (km)
40
35
30
25
20
15
10
5
0
380
370
360
350
340
330
1-Mar-10
1-May-10
1-Jul-10
31-Aug-10
31-Oct-10
31-Dec-10
2-Mar-11
Date
Total Dose
Running Average
Location Change
-Xvv [Shuttle Docked]
Altitude

Summary

In the new era of long-term human space exploration, opportunities in the area of Technology development in

- Biomedical research –

  Human Adaptation and Countermeasures
- Human Life Support –

  Environmental and Radiation Sensors

Acknowledgement

- Outstanding Scientists and Engineers from Wyle, USRA, Universities and NASA/JSC
- Ms. Melody Anderson and Dr. Neal Pellis, Ex NASA/JSC

- Intramural NASA Funds



"No pessimist ever
discovered the secrets
of the stars...

or sailed to an
uncharted land...

or opened a new
heaven to
the human spirit."

Helen Keller

Building a System : Bioreactor, An Example

